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Putting the railway underground in Catalonia: a complete picture

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ABSTRACT

The numerous negative impacts of above-ground railways, among them noise, risk and community severance give rise to a widely shared disapproval of their presence within urban areas. Nowhere is this more of an issue than in Catalonia. Residents of severely affected cities relentlessly urge the authorities to put the railway underground. The very high population density of Catalan cities and the often bad integration of the railway are the main reasons that may explain why this is such an issue in Catalonia and not in many other parts of Europe. The true necessity of putting the railway underground in certain locations is often questioned; and indeed, this action should be seen as the last resort when there is no room for alleviation measures. There should be a set of criteria to identify candidate locations where it is really justifiable to modify the course of the railway; it is the aim of this thesis to list out and thoroughly justify them. Based on these criteria, a thorough analysis of the integration of the railway in several affected cities of Catalonia is the main focus of this thesis. From these analyses it appears that there is more room for alleviation measures than previously thought, which undermines claims to put the railway underground in several cities. Three of the five currently approved and not yet executed projects in Catalonia are found to be justifiable. Out of the other addressed cities, only *Figueres* is found to have both the conditions to justify a modification of the railway, and a favourable benefit to cost relation of the project, as compared to the other cities. This does not mean it is a priority project yet it should by no means be ruled out.

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1. Introduction

Railways have developed together with cities; as cities grow, so do their rail networks. Railways are therefore a characteristic element of urban areas. Are they; however, just another kind of linear infrastructure such as roads and power lines? Experience and observations show that the answer is “no”. Railways are perceived and treated much differently. In most urban areas where no measures have been implemented there seems to be an integration problem between railways and city; of different severity depending on the nature of the surroundings. More often than not, areas along railways show clear signs of decay and dysfunctionality. Furthermore, railways are responsible for several kinds of nuisance: physical (barrier effect), noise and a psychological component that must explain why their presence is more often repudiated than that of roads, which pose similar nuisance. These factors, along with the development of cities in the XXI century give rise to the question of whether above-ground railways still belong in urban areas. In Catalonia, there is an ongoing and ever greater movement which repudiates the presence of above-ground railways in urban areas, yet everyone wants to use train services and have them close by. Most of the time, the solution is found to be putting the railway underground. Several municipalities in Catalonia have been demanding this for decades. Knowing that the outcome of such a project is very positive for a city, it is no wonder that all residents join the cause and advocate for it relentlessly. However, it is the ministry of infrastructure who has to fund the projects. A limited budget and the benefits resulting from a project being largely social clearly mean that not every municipality can see their claims materialized. Important questions to answer are: are these claims reasonable in the first place? When are such claims justifiable and not a whim? Are there no alternatives?

2. Goal and scope

The goal of this thesis is to understand the issues surrounding the relation between railways and urban areas, to find the most appropriate solution within distinct physical contexts and apply them to a set of real cases.

To start out, there are several questions which are expected to be answered as different aspects are addressed. The first question is whether putting the railway underground is the best solution to the railway integration problem. Related to the latter, we would like to study the possible alternatives and their applicability. With this, the goal is to identify the characteristics of the locations where these alternatives do not apply and putting the railway underground may very well be the solution.

Another dilemma is how urban planning authorities should deal with railways. There are several possible approaches; namely, not intervening and putting up with the bad integration of railways and all the problems arising from it; taking measures to ensure harmony between city and railway or radically solving the problem by putting the railway underground. The author hopes this thesis will shed some light on the striking fact that in Catalonia, along with Spain, the third approach is commonly preferred over the second one as opposed to most countries in Europe.

The study shall focus on the particular situation of Catalonia. Several cities, affected by the presence of the railway will be addressed. In the first place, locations in which plans to put the railway underground have already been approved will be thoroughly analysed. The goal is to determine whether these interventions are in fact justifiable based on the particular physical context and room for alternatives.

Next, the situation of the railway in several more cities will be addressed. By means of a thorough analysis and first hand observations, which are necessary to complement the little information shown on aerial images, every aspect playing a role in the relation of the railway with the surroundings will be discussed. The likely outcome of a modification of the railway in every city will be compared to the outcome in the case alternative measures were instead implemented; as well as the likely cost of the former. Based on this, a recommendation will be made as to whether the railway should be put underground or alleviation measures should be adopted instead.

3. The railway as a barrier

The impact of linear infrastructure on the landscape in rural areas is well known. Entire ecosystems are affected by the barrier effect, which fragments populations by restricting movement within a region that used to be free of obstacle in its natural form. Any form of linear infrastructure has a negative impact in the form of barrier effect. Power lines, pipelines and roads pose all detrimental impacts yet not in the same magnitude. Among the numerous types of linear infrastructure, railways have a remarkably large impact. First, railways usually run on relatively short embankments, which means tracks do not lie much higher than the surrounding land; which makes it very easy for wildlife to cross them. Second, the layout requirements of railways, being stricter than those of roads, mean they usually run through areas which are more accessible to wildlife. Lastly, the sheer magnitude of rail rolling stock means any crash is most likely to have fatal consequences for any animal involved in it. These are some of the factors that contribute to the detrimental effect of railways in non-urban areas. This barrier effect can be applied to urban areas, and its effects on the population, yet with different forms of impact to those in rural areas. In the following chapters, this very impact will be analysed in depth.

3.1. The barrier effect in urban areas

Of the numerous impacts railways have on a city, the barrier effect, that is, the severing of the urban fabric, is by far the one that leaves the biggest mark. It consists of both the physical and psychological barrier that such an element represents. A barrier arises between two conflicting movements of distinct modes of transport where one of them has a dominant position over the other. Linear infrastructure is logically the first thing that comes to mind that causes barrier effect. Streets are not perceived as a barrier up to a certain traffic intensity and speed. The barrier effect starts to appear on streets with high traffic intensity and speed, where the movement of pedestrians, cyclists, etc. starts to be clearly affected. Of greater impact is the barrier effect caused by restricted-access infrastructure, which have a limited number of crossing points, which force detour on any mode of transport not belonging on them. This is the case for highways and railways. Those affected are not only people living by the barrier, but also those who cross it regularly, to go to work, shops, etc. Therefore, the affected area extends far beyond the strip adjacent to the barrier element. The barrier effect is different for every mode of transport, as facilities are not designed equally for all of them. For this reason, pedestrians, cyclists, motorcyclists, motorists and public transport users are more often than not affected differently by the barrier effect. This, in turn, leads to important distributional impacts. Since the modal split is not the same for different age, income, social and gender groups, the effect is not evenly distributed among the population. Therefore, if a certain infrastructure element has its greatest impact on pedestrians; children and the elderly are expected to be affected the most, as they rely on this mode of transport. The disruption caused by one of such barrier elements will ultimately lead to a modal shift in which those affected are forced to opt for different transport modes, usually reluctantly, while not solving the barrier effect and having subsequent negative effects such as the disuse of the street as a social space.

The two main impacts of the severance caused by a physical barrier are the lack of access and the enforced detour or delays. These impacts can be assessed by a series of indicators:

Accessibility: The ability of people to reach certain destinations, using a certain mode of transport. Losses in accessibility to important facilities contribute to the social exclusion of communities. This indicator can be quantified by both the number of accessible destinations and the travel time to reach them. For example, a reduced pedestrian accessibility means that even if a destination is reachable, an increased travel time or detour may put people off the trip and opt for more attractive destinations or not travel at all. This may result in a remarkable loss of population interaction.

Crossability: The ease or difficulty of crossing the barrier (road, railway, etc.). It assesses the barrier attributes and user behaviour. Attributes measured are things such as the density of crossing facilities, width of the barrier, delays experienced while crossing and hesitation to cross.

Walkability: The connectivity or lack thereof of the street network which allows for smooth flows of pedestrians. A barrier which obstructs the pedestrian network in the form of a dead end or by forcing excessive detour has a very negative impact on the propensity to walk of a certain community, may it be as a mode of transport or for leisure.

Quality: The quality of local mobility can be compromised by the presence of a barrier. The psychological component of the presence of a barrier plays a major role here. Perceived pleasantness and safety may influence the quality of the trip and prompt people to change their route. This is most noticeable among pedestrians or cyclists. Actions such as avoiding a busy street because of a high traffic intensity, avoiding underpasses or areas with poor lighting because there are perceived as unsafe, all contribute to the route and mode of transport selection.

All in all, barriers to mobility have a detrimental effect on people's wellbeing due to forced detours, delays, perceived danger and several other reasons. This may be avoided by opting for a different route, mode of transport or not travelling at all, which results in a loss of social cohesion *(ref.1)*.

3.2. Impacts of the railway on a city

3.2.1. Positive impacts

Railways have always been linked to prosperity and population growth. The presence of a railway station in a city generates a considerable amount of economic activity, with both direct and indirect job creation. The presence of commuter train services, especially to a larger city, results in an increase of property value in the area *(ref.2)*. Socially, railways mean a dramatic increase in accessibility, particularly for certain population groups without access to other modes of transport. The presence of the railway also means that, to some extent, fewer journeys are made by car. This results in less pollution and better air quality, to the benefit of residents. For these reasons, it has always been attractive for people to live in such cities, a trend that is still observable these days in which more and more travel options are available and the use of the car is more widespread than ever before.

3.2.2. Negative impacts

Just like the presence of the railway has positive impacts on a city, listed out above; it also has numerous negative impacts which arise from its nature of linear infrastructure. They are normally (partially) compensated by the positive effect of a railway station, hence areas through which the railway runs but no trains stop, do not see any compensation for these negative effects, whose perception may in turn be accentuated.

The negative impacts of railways can be summarized by the barrier effect, which has a physical and a psychological component.

As a physical barrier, railways result in a lack of accessibility and forced detour or delays. Let us assess the previously introduced indicators for railways in urban areas.

Accessibility: Above-ground railways have a severing effect. Since access is restricted to rolling stock and maintenance staff, the possibilities to cross are theoretically limited to the locations designed for such function. This normally small number of crossing points means detours are significant. Travel times for motorized traffic, cyclists and particularly pedestrians increase considerably. The latter two are particularly affected, because of their lower speed. This may result in a modal shift to motorized traffic, with consequences such as pollution and noise; or a suppression of trips. This problem is already found along most existing railways, on which the present thesis focuses. Accessibility levels along the railway within an urban area can be greatly improved by the presence of underpasses and overpasses, although only partially, since some of these structures are not accessible for cyclists and disabled people. If railways run on a viaduct, elevated from the street level, accessibility is obviously much greater than if they do at ground level.

Crossability: Most crossing points within urban areas consist of either underpasses or overpasses, sometimes shared between motorized and non-motorized traffic, sometimes not. They are usually located far apart and usually involve some effort (walking up and down stairs). This prompts some people to recklessly walk across the tracks, in absence of a fence. If, conversely, crossing points consist of level crossings, there are some additional impacts that reduce the crossability indicator of the railway. First, the delay experienced while waiting at the barriers adds up to the already longer travel time. Second, there is a certain risk involved in crossing the tracks which, although being minimal, is always present because of the dramatic consequences an accident can have.

Walkability: Many streets intersecting the railway are cut off in the form of a dead end. Likewise, the great majority of them do not give continuity to the pedestrian network with an underpass/overpass. This results in a pedestrian network with a severe lack of connectivity.

Quality: Pedestrians may perceive underpasses as unpleasant and unsafe as they are usually narrow and poorly lit. In the case of level crossings, the situation is worsened by the perceived risk while crossing, which despite being comparable to the risk of crossing a street; is psychologically greater as trains are perceived as more imposing than cars or lorries.

Other effects arising from the physical barrier impacts are:

Noise: Trains are known for being noisy. Despite most railways not having as much of an intense traffic as streets, frequencies in urban railways are considerably high. This means noise is not sporadic but persistent. Persistent noise can have very negative consequences on the wellbeing and health of residents. Rail noise levels are estimated at around 80-90dB at a distance of 15m, depending on the speed and typology of trains *(ref.3)*. Noise increases with speed and is greater for freight trains than passenger trains. A good estimate of the noise level at 15m is 85dB, for an urban area with moderate train speeds. Noise levels decrease rapidly with distance, as can be seen in Figure I. For distances above 500m, railway noise levels are comparable to background noise during the day; hence it proves imperceptible, albeit it may stand out at night. A noise level of 70dB is considered a safe threshold as a persistent yet not constant noise *(ref.4)*. Figure I shows such noise level is reached at distances of about 100m. Besides the noise, railway circulation may produce vibrations that are perceived in adjacent buildings, proving unpleasant to residents.

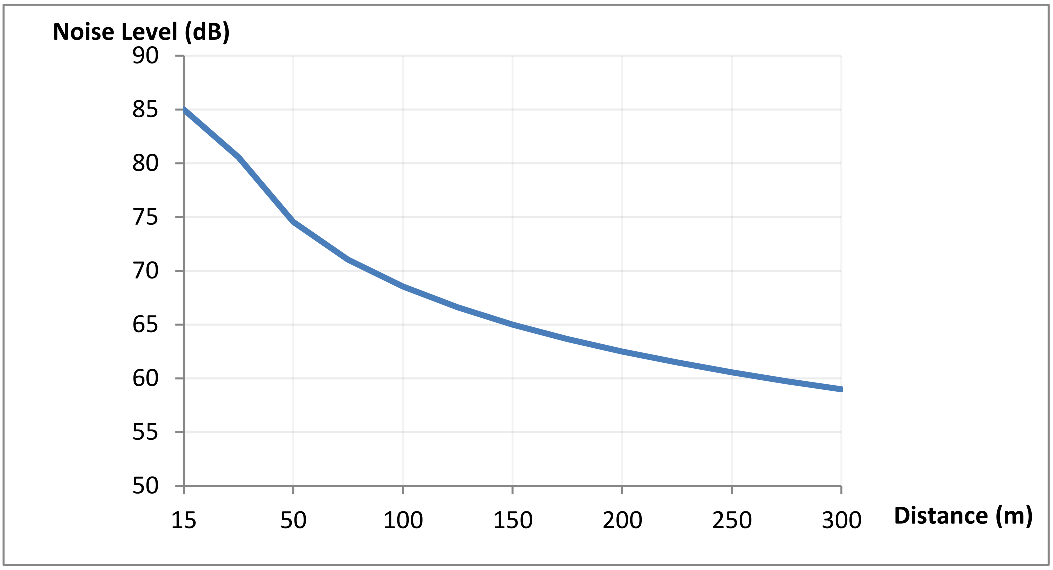

Figure I: Decay of noise level with distance from a railway line with average traffic intensity.

Visual Intrusion: The presence of the railway acts as a visual hindrance for both residents and passers-by and regarded as an unpleasant sight. Even if motorized traffic roadways are not as pleasant as a park or forest, they are generally preferred over railways. This has a negative impact on property value along railways.

Railways also have several psychological barrier impacts, which include unpleasantness, discomfort, perceived danger and loss of sense of place. All of these factors have a mild but steady detrimental effect on the quality of life of people.

The barrier effect; however, may also have positive effects on a community. Usually, partial isolation of a residential area means it does not see nearly as much traffic as if it was readily accessible and connected to the rest of the network, making it quieter than otherwise. To this extent, noise effects may be lower overall provided the infrastructure element causing the barrier has moderate noise emission levels or it does not lie immediately adjacent to residential buildings. However, the rest of the barrier effect remains present.

4. Putting the railway underground

The severe barrier effect of the railway prompts urban planning authorities to strive for railways that run underground. The great majority of the population of an area would rather have the railway put underground if given the option. For this reason, many municipalities with above-ground railways advocate for the intervention, which has effects on both the city and the railway operation.

4.1. Effects on the city

The first effect of putting the railway underground that comes to mind is the total disappearance of the barrier effect. This is not necessarily the case. While a long strip of land is relieved, if it is not put to good use, the effects may not be very noticeable. Relieved land may be primarily devoted to either non-motorized or motorized traffic. If the latter option is adopted, it may create a barrier effect on non-motorized traffic. A reasonable option is to devote most of the relieved land to non-motorized traffic and some parts to motorized traffic. This way, a positive effect on accessibility for both transport modes is ensured.

Converting the relieved land into a car-devoted avenue would not improve the barrier effect. In such case, the four indicators previously introduced, improve only very slightly. Noise levels, for their part, may even increase, depending on the traffic intensity of the new road and the former above-ground railway. Road traffic is responsible for noise levels of around 75dB, lower than those of railways, but because the traffic intensity is substantially higher, the perceived noise may increase. Furthermore, exhaust emissions are another negative factor that comes into play, which was missing in the list of effects of the railway. Even if, psychologically, the presence of a road is perceived as better than the railway, physical effects prove that a busy road is as much of a barrier. Nevertheless, in urban areas with heavily congested streets, devoting the relieved land for road traffic may be beneficial, still, the pedestrian network should not be neglected, as the new situation is likely to encourage more people to walk and/or cycle.

In short, if the space formerly occupied by the railway is reconverted properly, the effects on a city are overwhelmingly positive. The disappearance of the barrier effect means communities are brought together, allowing for more interaction and increasing social cohesion. Lifting the barrier also results in a better quality of life in a more pleasant environment. Increased accessibility means a modal shift from motorized to non-motorized traffic is likely to happen, with its consequences of reduced congestion, pollution, noise and risk. In most urban areas where other factors such as the terrain are favourable, the potential for a modal shift to walking/cycling is substantial; yet the conditions have to be created first. On top of that, the disappearance of the barrier might also stimulate the economy of the area as well as increase property value.

4.2. Effects on the railway

While the effects on the city are overwhelmingly positive, the effects on the railway itself are not as good. When it comes to rail operation, maintenance of tracks and overhead lines becomes more difficult and expensive. Getting staff and machinery underground is not as convenient and practical as it is above ground. Moreover, the high cost of building underground railways and accompanying facilities means the dimensions and number of tracks of underground railways are very limited. For this reason, rail depots and sidings are usually out of the question. They are very convenient for both maintenance and train operation. On top of that, underground railway facilities face several challenges that might add to the equation. Things such as a shallow water table or a settlement propensity of the ground are all too often experienced. When it comes to the service, as a direct consequence of the lack of sidings, train operation is to some extent constrained as the latter are needed to provide terminus services. This may result in the obligation to use the new underground station exclusively as an intermediate stop. On top of that, during the construction phase, temporary but intense disruption of the railway service is to be expected. What is more, if the construction works come to a standstill, because of whatever reason, the train service may be interrupted indefinitely. This is a risk that always has to be considered, and definitely adds to the costs. On the other hand, the fact that trains run underground means they can reach much higher speeds than they did above ground due to noise and the risk of running over people no longer being a constraint.

4.3. Alternatives to putting the railway underground

Laying railway tracks underground is a very costly solution. It could be described as the last resort to solve the barrier problem. If the latter can be successfully alleviated by other means, any proposal to put the railway underground is undermined. Several elements and/or actions can mitigate the impact of railways:

Overpasses: They very much depend on the railway level with respect to the surrounding streets. If the railway runs at the same level as the street, they must be of great dimensions to allow for enough height clearance for the railway below. In locations with limited space, this may very well prove unfeasible. By contrast, pedestrian-only overpasses are still an option, but their low accessibility for cyclists and the disabled and the added effort involved to use them make them unattractive and may even prompt people to the imprudence of walking across the tracks.

Underpasses: They are somewhat easier to accommodate; however, they also need high clearances if lorries or buses are to use them. Underpasses for non-motorized traffic are relatively easy to implement, but are usually not made adequately. Good underpasses should be wide, to provide confidence and safety to pedestrians, rather than narrow corridors.

Green walls: Another option to mitigate the unpleasantness of the presence of the railway is to “disguise” the barrier. Anything from hedges to trees along the railway can contribute to blur its presence. Extensive vegetation certainly creates a more pleasant situation both psychologically and physically, since vegetation can act as a noise wall.

Commitment: In some cases, the barrier effect can be substantially alleviated just by refurbishing old and decayed facilities that result in the surroundings of railways become increasingly run-down and dysfunctional areas. This takes commitment from both the railway authority and municipality. More often than not, it proves difficult for both institutions to work together towards a better integration of the railway. Measures such as removing unused sidings and train depots, reconditioning neglected fences or enabling access to stations from both sides instead of one, may be applicable to some situations and mean a great improvement. All of these measures are to be taken after removing all level crossings, if there are any. Pretty much everyone agrees that level crossings do not belong in urban areas. Yet, in cities like Tokyo, Japan; with a medium-high population density, railways run at ground level, which means most crossing points consist of level crossings. This makes one wonder whether the latter can in fact coexist with urban areas. The situation in Tokyo has to do with a particular physical context in which level crossings are proving increasingly ineffective. It is certainly not to be looked up to.

One might think the abovementioned measures are enough to alleviate the barrier effect. They are indeed in the great majority of cases, but in certain extreme cases, putting the railway underground is a better option. With this, the author wants to make the point that adding a great number of overpasses and/or underpasses is not always the solution. Their applicability has very much to do with the street layout, something which will be addressed in coming chapters.

4.4. Costs

The financial costs of putting the railway underground are substantial. These costs can be broken down into two main components:

Structure: The simplest and most applied method to bury roads and railways at a shallow depth is the cut and cover method. This is a relatively easy and inexpensive method compared to other forms of tunnelling. It is executed from the surface and involves the excavation of a trench and the construction of two retaining walls as well as a bottom and top slab, all of reinforced concrete. Costs of cut and cover tunnels lie around 20M€/km. Costs are for double track railways; covering more than two tracks drives up the costs and proves complicated in many cases.

Facilities: New railway tracks, electrification and balises are required, which total around 1M€/km. If a station is to be constructed underground, costs increase substantially. Maintenance costs are also bound to increase slightly, for the sole reason that the railway runs underground.

The cost of putting railways underground might be underestimated at first. This is due to, on the one hand, a very strict requirement for the longitudinal slope of the railway, which means it is necessary to dig a trench along a much longer stretch than what is actually going to be covered, which in turn means replacing a longer section of tracks and facilities. On the other hand, difficult geotechnical conditions such as a high water table may require an extensive drainage system to be installed as well as possible additional maintenance costs to cope with recurring groundwater problems. In short, overall costs might be higher than expected.

4.5. Valuation of social benefits

Putting the railway underground is a type of project whose repercussion is chiefly social. The benefits arising from improved life quality of citizens are remarkable, yet intangible. For this part, benefits are difficult to monetize. However, some effects can be valued. Noise can be assigned a price, namely the property value decrease per noise level increase, or vice versa. Noise effects on health prove difficult to be assigned a value because of their nature of indirect impact, despite being very real. The disappearance or alleviation of the barrier effect can have, as stated early on, positive economic effects on a city, resulting from the increased interaction among the population and creation of more opportunities. These benefits are, however, as difficult to measure as they are small as compared to the usual investment costs to put railways underground. The barrier effect can also be valued, by different methods. One of them is quantifying the time lost in forced detour and/or delays. This, however, monetized with the average value of time of residents gives; yet again, not very significant figures. Another option is conducting stated preferences surveys to learn about the citizens' willingness to pay for the railway being buried; which is a quite accurate way to ascertain the value of the barrier effect *(ref.5)*. Either way, because of the numerous intangible factors, the barrier effect should be quantified higher than what the raw monetary costs or benefits amount to. If a project appraisal is performed, all the previously listed effects should be incorporated and compared to the investment sum. Projects whose main goal is to alleviate or suppress community severance turn out to be, more often than not, not worthwhile from an economic perspective, yet this does not completely undermine them. Many could argue that projects with largely social benefits are not worth the investment. There are however numerous examples of cities where the railway was put underground in the past where social and economic benefits have been such that the original situation where the railway ran above ground is inconceivable. In short, social projects are worth the investment as long as costs are not unreasonably high and benefits are considerable, which means they have to involve many people.

4.6. Criteria to put the railway underground

As previously discussed, putting the railway underground is a costly undertaking that delivers limited economic benefits; however, the social benefits that can be achieved may, in some cases, back it up. Most residents of cities that are affected in some way by the railway barrier effect would like to see the railway put underground. But this is neither financially possible nor necessarily beneficial for the city. At the end of the day, cities and villages located along the railway benefit substantially from it, as discussed in section 3.2.1, so it can be argued that it is fair that they accept the nuisance and other drawbacks that come with it. Many people will ask themselves if it is wise to fund such projects when those funds could be allocated elsewhere. As previously mentioned, putting the railway underground should be seen as a last resort, and be ruled out when there is room for other less drastic approaches from which both city and railway would benefit. Such undertakings should be thus contemplated as the remedy for a serious problem and not as a whim. In the light of all these reasons, and to ensure correct and rational approaches to barrier effect problems, it is the goal of the present chapter to come up with an appropriate list of criteria as to when the conditions that justify the railway being modified are met. Several factors will be considered in order to make the most rational and fair of the analyses. The proposed criteria are; however, not to be followed blindly. At the end of the day, every city is different, and attention should be paid to every particular case.

Severity of the barrier effect: The first aspect to be analysed is how much of an impact the railway has on the concerned urban area. The first factor to consider is what degree of severance there is. The larger the areas divided by the railway are, the more severance there is. According to this, if a railroad runs close or through the city centre, the barrier effect is much greater than if it does in the outskirts. Nevertheless, if a relatively small residential area is cut off from the rest of the city, the barrier effect may still be considerable, all depending on the characteristics of the residents. In any case, this only applies to predominantly residential areas; hence a railroad separating a residential area from an industrial area poses a negligible barrier effect. The second factor is whether communities are cut off from basic facilities; that is, if residents have to cross the railway to reach hospitals, schools, shops, etc. These facilities are deemed essential and should be within reach of everyone; the presence of a barrier means they are sometimes difficult to get to. The third factor is the traffic intensity of the railway concerned. Even if this does not change the physical severance, the presence of the railway does not prove as unpleasant if trains run every hour as if they do every ten minutes. To sum up, candidate locations to put the railway underground must have residential areas separated by the railway and in particular, they must be cut off from basic facilities; and the traffic intensity must be reasonably high. Threshold values of 500 affected residents and a train frequency of two trains per hour in either direction are proposed by the author as minimum criteria to consider modifications of the railway in the first place.

Possibility of implementing alternatives: Alleviation measures, previously introduced in section 4.3, are not always applicable. Their feasibility depends on the immediate surroundings of the railway. If the latter runs in a trench, overpasses are very likely to fit within the physical context; if it does at the same level as the surrounding land, they may prove unfeasible to fit in. The contrary also applies to underpasses. The main constraint is space; the lack thereof may also rule out the implementation of green barriers or other “disguise” strategies. On the other hand, a great availability of space on both sides of the railway often means overpasses and underpasses fit well across ground level tracks; which means level crossings may be easily replaced by one of these alternatives and not necessarily give a reason to put the railway underground. In short, if alleviation measures can alleviate most of the barrier effect, modifying the railway is out of the question.

Population density: To justify the railway being put underground, there must be a reasonably large number of people benefiting from it. This does not mean only big cities meet this criterion, but small villages likely do not. However, particularly when it comes to noise, which is one of the most noticeable effects of the railway, there is a certain distance from the tracks where this effect is really perceptible and its exposure harmful. In section 2.2.3, this distance was identified as a hundred metres. It is therefore proposed that there should be a minimum number of residents within this 100m strip on either side of the tracks. This corresponds to the local population density. It is not the same if the railway borders single-family houses as if it borders buildings. This only applies to residential buildings. Office or commercial buildings are not considered to experience major nuisance from noise. A threshold of 10000 residents per square kilometre within the affected 100m strip is proposed. Figure II shows an aerial view of a low density urban area, as compared to a high density urban area, in Figure III. In the latter, it is clear that many more households are affected by the presence of the railway.

Physical context: This aspect is chiefly related to a particular location, so it is difficult to assess in broad terms. A correct assessment requires analysing the particular physical context of the concerned location. Elements to consider are in the first place, the street layout. It has to be analysed whether putting the railway underground would relieve space that could be of great benefit for the community and well-functioning of the city. If the population density is high enough, a missing corridor, in this case occupied by the railway and not a street, could be enough to considerably damage mobility in the concerned urban area. Relieving such space could thus be of great desirability, due to the important increase in accessibility and decrease in congestion.

Figure II: Example of a railroad through a low density urban area.

Figure III: Example of a railway line through a high density urban area.

The immediate surroundings of the railway are of great importance in this analysis. The proximity of buildings to the tracks is one of the decisive factors. If buildings stand too close to the tracks, there may be a narrow street separating them (Figure IV) or no street at all. In such case, relieving the space occupied by the railway may be of great necessity to strengthen the road and pedestrian network, as it is understood that demolishing those buildings is never an option.

Figure IV: Example of a railway corridor with limited space between buildings and tracks.

The corridor occupied by the railway could be thus seen as the backbone of the city, which in such cases is missing. If, on the other hand, such corridor is wide enough that there are wide streets on both sides of the railway (Figure V), with appropriately wide sidewalks; relieving such space is not deemed a necessity. In section 4.3, the importance of harmony between the railway and the surroundings is stressed. If buildings stand far from the tracks and there is some sort of green barrier along the tracks, the impact of the railway is greatly alleviated. Depending on the particular situation, it may be more beneficial for the community not to convert the space occupied by the railway to a road, since noise might increase in the latter scenario.

Another aspect to be considered when discussing whether the railway should run underground which is sometimes disregarded is the climate. If in a certain place, very warm temperatures are experienced during a great part of the year; noise, particularly rail noise has a much greater impact, as residents tend to keep windows open. Cities in Southern Europe, thus experience, for this reason, more noise pollution than their northern European counterparts. Climate may therefore justify the railway being put underground in a certain region and not in another one in locations where the rest of railway impacts are similar.

Future urban development: Even if a railroad does not meet the criteria to be put underground in a particular city because its barrier effect is negligible, it may still be possible to consider the consequences that putting it underground may have on the envisaged urban development of the concerned city. Despite the buildings and respective residents not yet being present, the relieved space might make for a better street layout and mobility. However, as far as possible, and depending on every particular situation, local urban planning should be conducted in such a way that the railway is ensured to remain well integrated within the surroundings and can therefore remain above ground.

Figure V: Example of a railway corridor with abundant space between buildings and tracks.

Technical difficulty: As introduced in section 4.4, technical difficulty drives up costs substantially. The level at which tracks run as compared to the surrounding land is one of them. Railways totally or partially running on viaducts or high above ground level may prove prohibitively costly to put underground as the intervention most likely involves the disruption of the street layout and the existing underpasses. In rugged areas, such as Catalonia, the railway may run at a constant level yet run both elevated, at ground level and underground at the same time, because of the unevenness of the terrain. Modifying the railway course in such conditions may prove very costly. The presence of obstacles such as rivers may also make it unfeasible. The width of the railway corridor is another factor. Four parallel tracks are proposed as the maximum width that is feasible to build underground. If the number of tracks is higher, as is the case in some train stations and depots, a wiser solution would be to reduce the number of tracks, thereby constraining the service to a certain extent, or to keep the railway above ground altogether. Other technical challenges that may arise such as the ground conditions and the height of the water table are present yet disregarded for this purpose.

Future prospects of the railway: It is important to know the future plans for the concerned railway. While railways normally last for a very long time, a certain number of them may come to an end and fall out of use and be dismantled, either because they no longer serve their purpose or because a new layout is found to be more appropriate. For this reason, if a railway is to be put underground, there has to be certainty that it is going to be operational for many years to come. Consulting local and regional urban development plans may help identify those railways that are planned to be dismantled or replaced by tramways. In such cases, putting the railway underground would be out of the question.

5. The railway network in Catalonia

The railway network in Catalonia is made up of three separate networks, which have very distinct features:

High Speed Network: A standard gauge line, it is the newest of them three. It was built within the last two decades; being in the process, well integrated within all urban areas through which it runs; one of the reasons being its strict impenetrability and protection needed to avoid disruption due to its nature of high speed rail. In addition to that, high speed railways have a more constraint layout in terms of curvature for which usually, there are required to run underground. It runs through three of the four province capitals of Catalonia, providing them with high speed rail service. Because of the layout constraint, several intermediate cities and villages are crossed by the line. Within urban areas, it was either built directly underground or covered afterwards. The increased severity of the barrier effect (noise, high speed), caused by the high speed railway drove it under the surface. All these factors, along with an increased awareness of the local urbanism and community severance effect when designing the layout, completely relieved the barrier effect of the high speed network; at least for the present and near future.

FGC Network: A standard gauge line, consisting of two lines, it was built between the late nineteenth and early twentieth century. Despite its age, this railway poses remarkably low community severance in the urban centres through which it runs. This may be due to the fact that cities along railways of this network predominantly grew out from one side of the railway, keeping it as an outer border instead of an inner border. Although the FGC network came about several decades later than the conventional network, cities were far from developed at that time. Other indicators, such as the density of crossing points and the existence of level crossings (there are very few along the FGC network), are much more positive than along the conventional railway. The FGC network serves thus as an example of both good urban planning and good rail layout. The barrier effect posed by FGC railways is further reduced by its nature of light rail. The latter can be considered an intermediate between tramways and heavy rails. Light railways have a much lower impact than heavy railways, as they make less noise, have lighter and shorter rolling stock and have a reduced stop separation, which plays very much in favour of residents.

Conventional Network: An Iberian gauge line, such different rail gauge having most likely been conceived to deter the French to invade the Spanish territory by rail; it is both the longest and oldest railway network. It consists of several lines, the overwhelming majority of which were built in the late nineteenth century, with several upgrades taking place throughout the following century. It supports the great majority of commuter rail service as well as intercity and freight trains. It consists, thus, of heavy rail. The conventional railway was originally built in the immediate outskirts of the cities it ran through. The fact that the original course of the tracks has not changed in the slightest and cities have expanded from both sides of the tracks means the railway now runs through the middle of some of these cities. To make matters worse, bad urban planning throughout the late century combined with the evolution of railways as far as number of tracks, frequency and speed have resulted in a very bad integration of the railway in many urban areas. Buildings too close to the railway, bad zoning, low density and quality of crossing points and railways running at ground level are some of the reasons behind it. Since, for the most part, railways of this network were built at ground level instead of on a viaduct or in a trench, most crossing points consisted of level crossings, of which a certain number have since been removed and turned into under/overpasses. The conventional railway is then the only one having numerous level crossings within urban areas. The often long distance between stops and intercity trains travelling at high speed on the same tracks as commuter trains means the barrier effect is remarkably large. The conventional railway is therefore, by far, the one posing the most problems in urban areas in Catalonia.

5.1. The railway in the major urban areas of Catalonia

The course of railway within urban areas has been progressively adapted since its construction, by either putting it underground or elevating it. There are still many urban areas where the railway runs at ground level. Among them, some experience a much more severe impact than others. Overall, there are 42 municipalities with a population of over 5.000 where the railway runs above ground and creates some degree of barrier effect: on the railway *Barcelona-Maçanet*: *Sant Adria de Besos, Badalona,* within the rest of municipalities along the *Maresme* coast, the railway only separates the cities from the beach, so there is no barrier effect whatsoever as we know it; on the railway *Barcelona-Portbou: Montcada i Reixac, Mollet del Valles, Granollers, Sant Celoni, Girona, Celra, Figueres*; on the railway *Barcelona-S.Vicenç: Cornella de Llobregat, Sant Feliu de Llobregat, Molins de Rei, Vilafranca del Penedes, El Vendrell*; on the railway *Barcelona-Valencia: Hospitalet, Vilanova i Geltru, Sitges, Cubelles, Cunit, Calafell, Altafulla, Torredembarra, Tarragona, Salou, Cambrils*; on the railway *Barcelona-Lleida: Montcada i Reixac, Barbera del Valles, Terrassa, Sant Vicenç de Castellet, Cervera, Tarrega, Lleida;* on the railway *Barcelona-Puigcerda: Montcada i Reixac, Santa Perpetua, Mollet del Valles, Canovelles, Granollers, La Garriga, Centelles, Balenya, Vic, Torello, Ripoll*; on other railways: *Reus, Valls*. Of the municipalities on the list, some experience a much larger impact than others. On a map or aerial photograph, some cities may appear to suffer major nuisance from the presence of the railway, yet this turns out to be untrue if the assessment is made on the spot. This is the reason why, to really understand the situation, it is necessary to know the concerned place first hand. In the capital of Catalonia, Barcelona, all railways either run underground or are due to do so. The fact that several railways meet, (or spread out) in the city, makes for very large areas to cover; which poses severe financial as well as technical difficulty to execute the works. Some of the municipalities on the list have claimed or still claim to have the railway put underground. As of today, some cities have withdrawn these claims, knowing that the government is not likely to fund such projects if they are not considered a priority. The municipalities that are currently urging the government to lay the tracks underground are mostly those where a level crossing is still present. They use this to justify their entitlement to have the railway put underground. However, if those level crossings can be feasibly replaced by an alternative and the barrier effect is thereby alleviated, those claims get undermined. Every situation needs to be assessed thoroughly and independently. On the other hand, several municipalities such as those located on the *Maresme* coast, may show some features that may justify the railway being covered; and it may prove beneficial for both mobility as it would enhance the street network; yet the barrier effect as we know it is not present as the railway only separates the city from the beach, as can be seen in Figure VI; therefore, everything points to the railway remaining above ground. Some may argue that the barrier effect is present, yet the waterfront is no more than a leisure element, which means it does not fit in the definition of community severance.

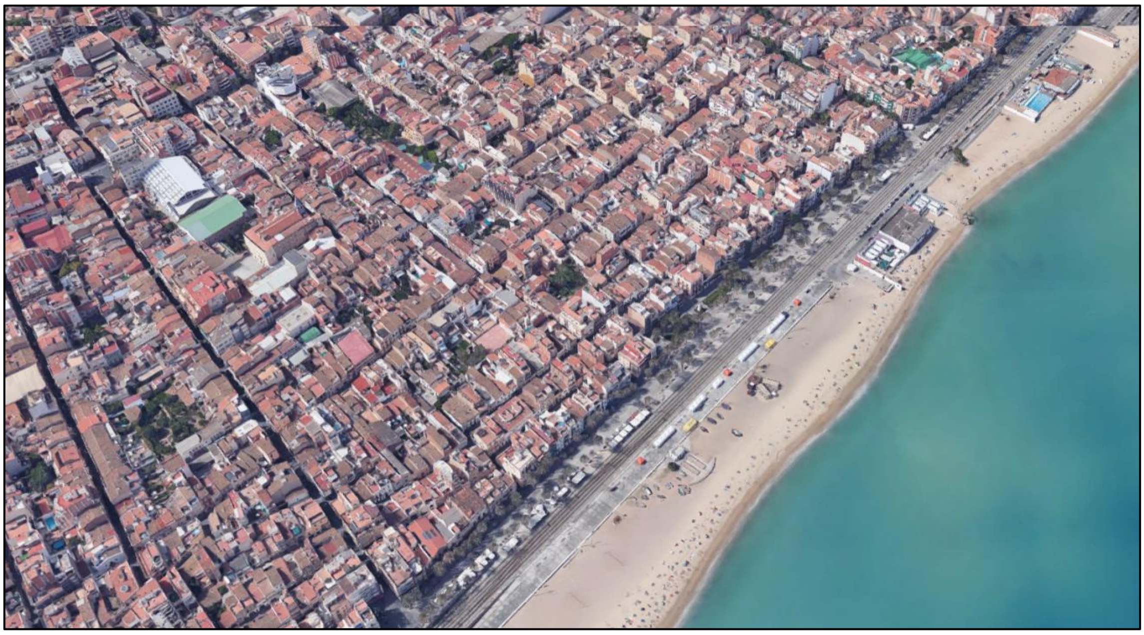

Figure VI: Example of a railway corridor with no barrier effect.

What most urban areas on the list have in common is the fact that the railway came before the buildings and streets around it were built. Some people use this to claim that burying the railway is not justified. This claim can be easily undermined by the fact that most railways in Catalonia were indeed built before the surrounding buildings, yet as cities grew in size and population, the railway no longer fit above ground, and had to be adapted to the new environment, namely put underground. It is thus a matter of time until the space occupied by the railway has to be relieved, and in some urban areas of Catalonia, such time may already be due. Cities along railways in Catalonia suffer from an intensified barrier effect as compared to other countries due to several factors: In the first place, buildings normally consist of attached units, arranged in such a way to form full blocks, and those buildings are usually made up of several housing units. On top of that, streets are usually rather narrow. This is the norm in most countries of Southern Europe, where urban planning is constrained by the lack of space brought on by the fact that in a large percentage of the area, the terrain is too rough to build on. This all means the population density is very high within urban areas. To make matters worse, buildings were erected too close to the railway from the very beginning. This could be attributed to both the lack of space and a poor urban planning with no long term vision practised all throughout the twentieth century. If, yet again, the factor of the climate, which magnifies the effect of the noise, is added to the equation, we end up with a severe impact of the railway. Residents of the urban areas affected cannot be held accountable for the urban planning mistakes made in the past, which in most cases are irreversible. It is thus just fair to put the railway underground in places where it is proven to cause a serious barrier effect.

5.2. Comparison with other countries

One of the multiple objections that arise when a city in Catalonia considers putting the railway underground is that in most countries, railways run above ground through urban areas, and although disturbance is sometimes considerable, it is not even thought of burying the railway. While this is a fact, physical contexts are different, and might make comparisons unrealistic and unfair. Let us analyse the situation of railways within urban areas of some European countries and try to compare them to those in Catalonia.

In most major cities of Europe, train stations are of the type terminus. This means they sit above ground, are very large and have a large number of tracks. Rail yards and depots are usually also located within the city centre. This all makes for very large spaces occupied by the railway, which are just not feasible to modify. This is the case in cities like Paris, London, Madrid, Zürich, etc. In Catalonia, rail yards have been progressively dismantled throughout time, especially those lying within medium to high density urban areas. This has proven to have overwhelmingly positive effects as far as urbanism, mobility and integration goes, yet it proves a constraint for railway service, as rail storage and maintenance facilities become limited, as is the case in Barcelona. A trade-off should be found. The only rail yards in the city of Barcelona are *Sant Andreu* and *Can Tunis*, both of which lie within industrial areas, unlike rail yards in many cities across Europe, which lie in the city centre, as can be appreciated in Figure VII. While in cases such as those in Figure VIII it is out of the question to put such a vast number of tracks underground, it does not mean it is the wisest option to leave it as it is.

Figure VII: Example of a rail yard in an industrial area: Can Tunis.

Figure VIII: Example of a terminus station and large rail yard within an urban area and resulting barrier effect: München Hbf.

The barrier effect these rail yards create is substantial, particularly in areas with high population density. It would be a wise option to determine whether such rail yards are not in fact derelict or such large number of tracks is necessary. Dismantling part of the rail infrastructure would certainly alleviate the situation at a relatively low cost and enable underpasses/ overpasses to be built across the tracks. This is, however, easier said than done. Despite railway authorities usually consisting of state owned companies, they are seldom eager to give up land to the municipality at the expense of the service/maintenance work being constrained even a little bit. There is thus a great need for cooperation between municipality and rail authority, which is all too often missing.

Let us now consider railways with a reduced number of tracks, which may run through large or smaller cities but far from the main stations. If we have a look at the course of the railway through urban areas in Europe, we see that almost all of them run above ground. When compared to Catalonia, the percentage of railway network running underground in other countries is much smaller. There must be reasons for this, right? It turns out there are several factors that may explain this difference.

Population density: As noted in section 4.6, population density is a key factor when assessing the barrier effect. The number of people living in one area determines the density of the interaction network; when a barrier stands across this network, the latter is disrupted. The more people living in a particular area, the greater the disruption is. In section 4.6, it is also mentioned that southern European cities are denser than northern European cities. This difference in density is just as big in large and small cities. Urban areas in Catalonia have a particularly high population density. The situation in the rest of Spain is very similar to Catalonia, as settlement patterns have been roughly the same throughout history; however, cities may be denser in Catalonia due to a more rugged terrain and the subsequent lack of space. The arithmetic population density of Spain is relatively small (93p/sqkm), placing it on the bottom half amongst European countries, and Catalonia (229p/sqkm) lies above average but far from the most densely populated countries. This may give the impression that they are sparsely populated; however, if we calculate the lived population density, that is, considering only populated areas, we may catch a better glimpse of how close together people in Spain live. Let us divide the surface of a country into a one-square kilometre grid. Of those cells, we consider those that are inhabited. Calculating the population density over such area gives much larger figures than before. The outcome can be used as a good estimate of the real population density. In Figure IX, we see the results of this calculation if it is performed on every country in Europe. The outcome is striking; Spain comes in fourth at 737p/sqkm; only behind the likes of Andorra, Malta and Monaco, which are all microstates. It turns out Spanish urban areas are the most densely populated of all of Europe. City layouts are nowhere as dense and nowhere are buildings so packed as close together as in Spain *(ref.6)*. As mentioned earlier, this situation further intensifies in Catalonia. Despite the value of the lived density in Catalonia not appearing on the chart, it is somewhat higher than in the rest of Spain. Several of the most densely populated urban areas in Europe are in Catalonia, and of those one-square kilometre cells, out of the twenty most populated, ten are in Catalonia. This pattern does not only appear in the capital Barcelona and its suburbs, but is rather the norm in most urban areas in the region.

Country	Land Area (Sq Km)	Arithmetic Density	Built-up Density ('Lived Density')	Max 1km population	Population 2011	% of 1km cells populated
Monaco	2	18,067	18,067	12,564	36,133	100.0
Andorra	468	182	1,525	9,300	85,406	12.0
Malta	316	1,316	1,382	11,421	415,891	95.3
Spain	505,634	93	737	53,119	46,814,568	12.6
Netherlands	37,321	446	546	23,485	16,627,680	81.6
England	130,279	405	531	20,477	52,697,866	76.2
San Marino	61	420	493	2,034	25,629	85.2
Italy	301,289	197	453	22,113	59,369,049	43.5
Liechtenstein	160	223	447	1,947	35,775	49.8
Belgium	30,544	358	434	29,100	10,939,956	82.5
Romania	238,262	90	402	19,179	21,387,361	22.3
Switzerland	41,289	191	385	21,456	7,899,058	49.6
Greece	129,639	83	379	28,880	10,801,047	22.0
Germany	357,473	224	376	23,379	80,004,386	59.5
Hungary	93,067	107	368	10,451	9,923,425	29.0
Slovakia	49,134	110	358	15,379	5,391,770	30.7
Cyprus	9,487	88	319	5,439	839,063	27.8
Bulgaria	111,073	66	312	23,934	7,364,570	21.3
Luxembourg	2,634	192	308	7,213	505,682	62.3
Portugal	91,632	115	255	21,823	10,560,578	45.2
Czech Republic	78,970	132	236	23,249	10,420,401	55.8
Austria	83,911	100	220	16,984	8,385,332	45.5
Isle of Man	572	147	212	4,654	84,293	69.4
Wales	20,735	147	204	11,291	3,038,049	71.8
Scotland	80,077	63	200	11,069	5,044,291	31.4
Poland	312,101	123	196	32,752	38,497,929	63.0
France	551,695	114	195	52,218	62,744,459	58.4
Iceland	102,285	3	187	5,738	318,700	1.7
Denmark	43,282	128	183	22,381	5,530,902	69.7
Croatia	55,443	77	161	10,202	4,271,221	47.9
Northern Ireland	14,130	128	160	8,555	1,803,600	79.6
Slovenia	20,340	99	153	10,504	2,021,380	65.1
Latvia	64,659	32	116	10,123	2,061,100	27.5
Norway	334,778	15	89	15,673	4,906,148	16.5
Lithuania	64,915	47	85	16,166	3,022,087	54.9
Sweden	450,133	21	84	26,120	9,539,483	25.2
Ireland	70,728	65	81	12,176	4,573,374	80.0
Estonia	45,445	28	62	17,375	1,290,520	45.5
Finland	336,751	16	53	14,933	5,338,841	30.1

Figure IX: Countries of Europe by lived population density.

It is thus easy to figure out why railways do not belong above ground in most urban areas in Catalonia. Railways that run through urban areas pose a great disruption to the urban fabric and occupy a space that is very valuable if population density is very high, and should thus be used for a distinct purpose, be it a park or a street. There are, however, many examples of very densely populated cities in Europe where railways run above ground. Examples are Paris and Brussels, which are not particularly cities to be looked up to, as they have some of the worst traffic in Europe. The presence of above-ground railways certainly does not help. These cities chose to elevate the railway on viaducts or embankments instead of putting it underground. This is a measure many urban areas have adopted over time. They may be a good option in low density areas or higher density areas where buildings stand far from the railway, as underpasses are straight and flat, or there is no need for them in the case of pure viaducts; yet, they do not belong in high density urban areas where buildings also stand close to the railway, because of the disruption they create in the form of noise and barrier effect. In Figure X, an elevated railroad in a high density area with a wide strip separating it from the buildings, with a wide and well equipped underpass is shown as both an example of a good integrated railroad within a city and a well-designed underpass. This can be compared to the situation in the city of *Girona*, in Figure XI, where the railway runs elevated along a street with very little space separating it from the buildings.

Figure X: Example of well-integrated elevated railway. Note the wide gap between buildings and railway, the wide underpass and the good aesthetics of the bridge. Location: Antwerp.

Figure XI: Example of poorly-integrated elevated railway. Note the narrow gap between buildings and railway. Location: Girona.

Street layout: To make matters worse, the street layout of cities in Catalonia is very rigid, which in turn gives rise to the high population density discussed previously. Blocks are generally completely filled with attached buildings and streets are relatively narrow, allowing in most cases only one-way traffic. On top of that, the terrain is in most cases unfavourable for walking and cycling so the modal share corresponding to motorized traffic is very high. This very factor also means underpasses and overpasses are not as easy to build, if they can be built at all, something which is determined by the distance to the adjacent buildings. Above-ground railways running through urban areas with these features just do not quite fit. Conversely, cities with different layouts, i.e. wider streets and detached buildings may host above-ground railways while experiencing a much lesser impact. Figures XII and XIII illustrate the difference in integration of the railway between two urban areas with very different layouts.

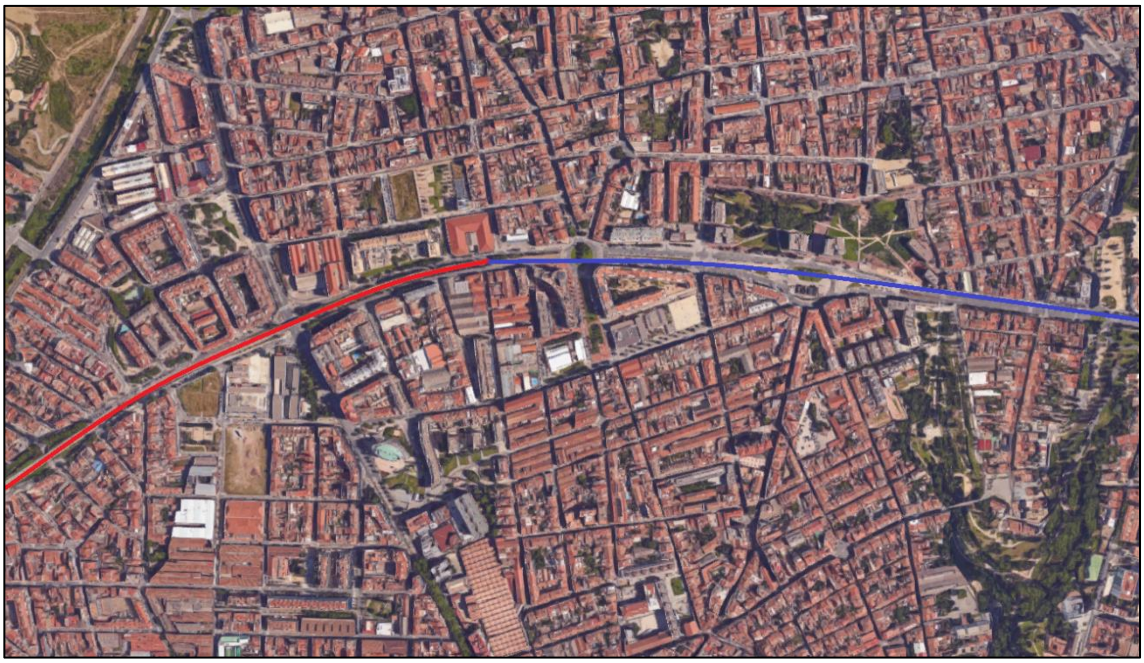

Figure XII: Example of a city layout where above-ground railways do not fit well. Along the blue segment, the railway runs underground; along the red segment, above ground. Location: Terrassa.

To these factors, as mentioned in section 4.6, we may add the climate. The high temperatures experienced in Catalonia during a big part of the year mean that noise is more present in the homes of people living next to busy roads and, particularly railways; than it is in colder countries.

All these factors help understand why conditions in urban areas of different countries are not really comparable and suggest that the argument: “Railways should be kept above ground in Catalonia because every other country does”, should not be followed blindly. The right approach should rather be to analyse every particular situation and decide what the best solution is.

Figure XIII: Example of a city layout where above-ground railways fit remarkably well. Note the wide streets and detached buildings. Location: Berlin.

The issue of railways and their impact on urban areas has been compared to other countries to understand whether putting the railway underground is a good strategy, yet this does not mean that we necessarily have to look up to them. By no means are urban areas in other countries of Europe exemplary in terms of their integration of the railway within cities; nevertheless, we can certainly learn a lot from them. Some strategies to integrate the railway, observed in cities across Europe, which could be applied to avoid putting the tracks underground, are the following:

Zoning: Developable land adjacent to the railway should be used for industry, or offices instead of residential buildings. An industrial zone definitely fits better next to the railway. If this is not possible, then buildings should not be built too close to the tracks; in the case of Catalonia, past urban planning mistakes should not repeat.

Aesthetics: If there is enough space between buildings and railway, several simple measures to alleviate the visual impact of railway tracks could be implemented. Trees, noise walls and well-maintained under and overpasses are examples often observed in other countries yet hardly present in Catalonia.

Accessibility: As discussed in section, another very simple but effective measure is enabling access to a railway station from both sides of the tracks. An underpass connecting the station building with the street from both sides is something we see in several cities across Europe, yet it is all too often missing in railway stations across Catalonia.

6. Possible modifications of the railway in Catalonia

As discussed in the previous section, modifying the course of the railway is not a commonly applied measure, yet when it is applied, usually in the form of putting the railway underground, it proves to be very beneficial. Questioning the feasibility or necessity of future interventions is a recurring action, yet nobody questions past modifications of the railway. The thing is that in Catalonia, the great majority of projects of this type have proven very beneficial for the cities where they were conducted. There are numerous examples of cities that cannot even imagine having the railway back above ground, for the radical change it meant. If these changes to the railway all proved so positive, why should not others do so?

The aim of the present thesis from this moment on is to analyse thoroughly the situation of the railway in some major cities of Catalonia, and by drawing on the parameters and criteria introduced in section 4.6, decide whether the course of the railway within such cities should be modified. This modification will most likely consist of either covering or burying the tracks. In the case such measures are not deemed to be necessary or appropriate; alternatives suiting best each situation will be proposed.

6.1. Recent examples

There are numerous examples of railways that used to run above ground and now do underground. Yet the great majority of these changes happened at the end of last century, which means the former situation is literally buried in the past and is thus no longer comparable to the current one, because of the long time that has passed by and the numerous changes cities have undergone in such time. The two most recent interventions of this kind were conducted in *Montmelo* and *Vilafranca del Penedes*, two cities with a similar shape and layout which the railway used to split in two. The conventional railway was likely covered because of the then new presence of the high speed rail, which runs parallel to the former, which would have meant a magnified impact, because of the higher speed and louder noise. Let us analyse the presence of the railway in those two cities and compare the former and current situations.

6.1.1. Montmelo

As can be appreciated in its former layout, Figure XIV, a railway line ran at ground level through this this small city of 8800 inhabitants, a figure which has experienced little variation over the last ten years. It resulted in the main part of the city being separated from a neighbourhood of some 1200 residents. While on the map, the barrier effect may appear to be severe, it was actually not so. Accessibility and crossability were very limited, as there was only one overpass across the entire railway segment. Pedestrian accessibility was also limited; and in spite of a footbridge (see Figure XIV) crossing the tracks to an industrial area, certainly not an optimal location; the enforced detour was up to 600m, or seven minutes on foot, for the farthest apart locations. Otherwise, the population density along the railway was not so high, with a percentage of the buildings consisting of warehouses and other industrial units. On top of that, there was quite some space between tracks and buildings, with parallel streets and enough room for trees; which combined with the shape of the terrain, which meant most of the city lied at a somewhat higher altitude with respect to the tracks, allowed for a wide underpass to be constructed at the same location of one of the newly constructed streets (leftmost crossing point in blue, see Figure XV). This would have greatly alleviated the barrier problem of the railway. This being said, it would not have been necessary to put the conventional railway underground, yet the then future presence of the high speed rail did justify such action, because of the magnified impact of the latter, described in section 5.

Figure XIV: How Montmelo used to look before the tracks were put underground. Note the only overpass (light red) and footbridge (dark red). year: 2008.

The fact that this action would not have been justified had the high speed rail not been constructed does not mean that it has not proven beneficial for the city. The current layout can be seen in Figure XV: two additional one-way streets connecting the two parts of the city mean the enforced detour is reduced to a negligible value for both pedestrians and cars and accessibility is as high as it can be within the city’s street layout. Yet the latter could still be improved if the central covered railway section, in yellow in Figure XV, was urbanized as a space for pedestrians, and the leftmost section, in yellow in Figure XV, was turned into a new street. This is most likely already planned yet the fact that such space still belongs to the railway authority and the interested party is the city council makes these seemingly easy projects difficult to realize. All in all, if such measures are implemented in the future, the shift from an above-ground to an underground railway will prove a true success for the city.

Figure XV: How Montmelo currently looks. Note the already existing overpass (light red) and newly opened streets (blue).

6.1.2. Vilafranca del Penedes

This city, just like the previous one, was split in two by the railway, as depicted in Figure XVI; however, the conditions were different. Even though the railway ran above ground, it did so in a trench. This means the city lay at a higher level than the railway. For this reason, there were several overpasses which simply consisted of a prolongation of streets across the trench. Of this city of 36000, a district with then some 2000 inhabitants lied on the other side of the tracks. This area was largely unexploited before the railway was covered, and a large part of it consisted of an industrial area. The barrier effect was not severe, and some improvements to the street layout could have easily been achieved by building a number of overpasses, which fit well due to the higher relative position of the city with respect to the railway. Buildings on the north side, however, stood close to the railway corridor, making for large visual and noise impacts. The long shape of the city meant the latter happened along two kilometres; which considering a hundred-metre wide strip affected by noise, as resulting from the discussion in section; and considering the high population density, namely 16000 p/sqkm, amounted to some 700 households. Such affected area would, yet again increase with the presence of the high speed rail. For the reasons density and noise, covering the railway might have been justified, yet not because of its effects on the street network.

Nevertheless, it has to be noted that this railroad was not put underground, but covered by placing a deck on top of the trench; thereby staying the tracks mostly at the same level along the covered stretch. This drove the investment down, which may have made the project attractive. Figure XVII illustrates the current situation, with newly opened streets in blue. Such streets have proven very beneficial to relieve congestion on the central overpasses, provide a better accessibility to a newly developed area and stimulate the growth of the city along a previously unattractive and dysfunctional area. The pedestrian network has greatly improved as most of the space of the former trench consists now of green areas (or they are intended to be so in the near future); however, good pedestrian accessibility could have also been achieved by means of building those same streets, in blue in Figure XVII, as overpasses across the tracks.

Figure XVI: How Vilafranca del Penedes used to look before the tracks were covered. Note the then present overpasses (red). year: 2003.

The railway was; however, not covered along its entire stretch across the city. As far as covering the remaining part goes, it is neither a true necessity nor feasible. The southernmost stretch of railway (bottom in Figure XVII) runs in a trench, yet the terrain is not even on both sides, hence if such stretch was covered, the relieved space would not be much useful. Besides, it is too short to have much impact other than noise. The northernmost stretch, on the other hand, is substantially longer (420m) and has a lack of crossing points. The railway does not run in a trench but at the same level as the surroundings, which rules out the idea of putting it underground because of the necessity to lower the entire stretch of railway that runs through the city, something that would prove too expensive for the little change achieved. The author's recommendation is to construct an underpass which would directly join two streets roughly halfway between the two nearest crossing points. This location has enough room to accommodate a wide enough underpass. See it highlighted in yellow in Figure XVII and in Figure XVIII.

Figure XVII: How Vilafranca del Penedes currently looks. Note the already existing overpasses (red) and newly opened streets (blue).

Figure XVIII: Possible location of an underpass across the ground-level rail.

Since the surrounding land is largely undeveloped, urban planning should focus on ensuring buildings are not built too close to the tracks in the future, something which has already been done, as the adjacent strip to the railway along this stretch consists of a green area. All in all, the shift from above-ground trenched railway to covered railway, although of questionable priority if it was not for the presence of the high speed rail, has had a very positive effect on the city.

6.2. Approved modifications

A number of cities along the railway plan to make modifications to its course, in most cases cover or put it underground. It has long been stated in their urban development plans; however, it is not yet certain if such projects will ever be realized. As of the year 2018, some of these projects seem to finally be brought forward because of their apparent necessity and numerous claims by residents, who conjointly urge the government to take action. Let us analyse whether such interventions are really necessary and justifiable and what impact they may have on the concerned cities.

6.2.1. Montcada i Reixac

This city of 35000 inhabitants is located right at the entrance of the only natural corridor linking the city of *Barcelona* with the industrial region of *el Valles*, and in turn with much of the northeast of Catalonia. This means the city is located at crossroads by nature. The same applies to railways. No fewer than three railways cross this city, at a short distance from each other. Despite all three railways having at least a stop within the city, to make up for the inconvenience; the city is clearly affected by their presence. The barrier effect is severe, as the railway(s) run at ground level right through the city and are considerably busy, with all three railways having headways under thirty minutes and some trains running past the city without stopping. The population density is very high, namely 24000 p/sqkm, and buildings stand very close together and to the railway, making underpasses either unfeasible or too narrow. Putting the tracks underground is a completely justified undertaking that is bound to be very beneficial for the city to relieve necessary space to strengthen its street layout and reduce the nuisance that the barrier effect and noise mean. Putting the railway underground in such a context is therefore a clear example of a high-priority intervention, which meets all criteria to be justifiable and should have been made long ago. The reason why it might have been disregarded over the years is the technical difficulty. The city of *Montcada* is anything but flat, and sits partly on a hill slope and across a river. Out of the three railways, one of them, the railway *Barcelona-Portbou*, which has the most severe barrier effect, is the most feasible to be put underground. Nevertheless, a section of the railway *Barcelona-Lleida* would also be justifiable to be put underground or modified, namely the stretch running through the city centre, in yellow in Figure XIX, as well as a stretch of the railway *Barcelona-Puigcerda,* in red in Figure XIX, because of the same reasons previously mentioned. The project to bury the first of the railways, in green in Figure XIX, appears to be approved yet its realization is uncertain. The reason behind its approval is the year-lasting claims made by residents, who appeal to the danger of the level crossings present in the city to justify the necessity of the project. Yet this should not be the reason to put the railway underground but the unfeasibility to replace such level crossing with an underpass and sheer severity of the barrier effect as described earlier.

Figure XIX: Possible modifications of the railway in the city of Montcada, note in green the stretch approved to be put underground and in red and yellow the two other possible and justifiable modifications.

6.2.2. Sant Feliu de Llobregat

In this city of 44000 inhabitants, the railway runs right through the city centre, thereby splitting the city in two roughly equal halves. As far as the population density within a 100m strip on both sides of the railway goes, it is not as high as in other cities but is still high at 19000p/sqkm. The barrier effect is only severe within the central stretch, which runs at the same level as the surrounding streets; with the rest of the railway running in a trench. Buildings do not stand as close to the railway as they do in *Montcada*, and there are wide enough streets on both sides of it; which means the street network can hardly be enhanced. However, within that central stretch, there is a level crossing and two narrow underpasses; which are unfeasible to be replaced by wider underpasses because of the lack of space. That level crossing proves to be very unpleasant for residents and it is the main reason why in recent years they have been urging the government to put the tracks underground. Closing off the level crossing is not an option because of the disruption it would have on the street layout. There is indeed something that needs to be done. The present situation could either be alleviated by putting underground that central stretch (see Figure XX); or implementing some measures though these are limited. These measures may consist of the conditioning of the two pedestrian underpasses just south of the railway station, in orange in Figure XX, to make them more attractive and functional, as they currently consist of narrow corridors, which makes them unpleasant. Putting the railway underground in this city would thus not be a priority like in *Montcada* yet it is perfectly justifiable.

Figure XX: Possible modifications of the railway in the city of Sant Feliu de Llobregat, note in yellow the potential stretch to be put underground and in orange the two underpasses to be conditioned.

6.2.3. Hospitalet

This is a municipality of 250000 inhabitants adjacent to *Barcelona*. Its total population density places it as one of the most densely populated municipalities of Europe, yet because its southern part consists mostly of industrial area; its actual population density is much higher. The northern part of the city is traversed by two railways that run at ground level and parallel to each other until they spread out at some point in the same city. The surroundings of the railway consist of buildings that stand very close to the tracks, with a very poor street layout, as buildings are very tightly packed together. They stand in fact so close together that the area just north of the railway is actually the most densely populated area in all of Europe, with 53000p/sqkm. This figure is enough to realize that a railroad should not run above ground in such location for the noise and disruption to the street layout it creates. Modifying the course of the railway through this city is something that has likely been on the table for years but could not just be realized because of the technical difficulty of such project. The fact that metro rail and high speed rail run directly or very close below the conventional railway and the terrain is very rugged make the project a difficult undertaking. However, it can very much be considered a necessity to either put the railway underground or cover it at along the stretch depicted in Figure XXI, while remaining at the same level to strengthen the pedestrian network.

Figure XXI: The city of Hospitalet, note in dark red the stretch to be modified. Note the population density within the one-square kilometre cell. No fewer than 53000 people live in it.

6.2.4. Granollers

A double track railroad runs through this city of 60000 inhabitants, and even if most of the city lies on one side of the railway, there is still a good 25% of the city on the other side. The population density is relatively high, at roughly 17000p/sqkm along the tracks, and buildings stand relatively close to the railway corridor. On the aerial photograph of the city (Figure XXII), it may look as if the barrier effect is severe; however, if we zoom in, we see that the railway only runs at ground level in the leftmost part of the image, and does so in a trench along the rest of its course. The present number of overpasses is satisfactory to ensure good mobility, and the lower level of the railway with respect to the surroundings means another one could easily be built if necessary. The presence of the railway is sure unpleasant for its noise and unattractiveness, as a large part of the surroundings of the railway are rather dysfunctional. Yet this could be greatly improved by refurbishing those areas, without the need to cover the railway. Renovation measures such as the one shown in Figure XXIII could be applied to more segments along the railway. Along the northernmost 700m (on the left, in red in Figure XXII), the railway runs at ground level and there are no crossing points apart from a footbridge. This creates a quite severe lack of accessibility between two areas, which despite sitting 50m opposite of each other, are separated by a 1200m detour. This is due to the fact that there is not enough room for an underpass. A possible option is to shift the tracks some metres to the west along a short section to accommodate an underpass, as there is enough room on the other side of the tracks, as shown in orange in Figure XXII. All in all, the railway seems to be sufficiently well integrated within this city and the situation could be further improved with some simple reconditioning measures; hence, although the city intends to do so as stated in its urban development plans, covering the railway in this city is not seen as a necessity.

Figure XXII: Aerial view of the city of Granollers, note in red the ground-level stretch that could be shifted to make room for an underpass.

Figure XXIII: Example of refurbishment of strips adjacent to a railway corridor. The green walkway on the right used to be a dysfunctional area. Now it is a pleasant place that makes up for the nuisance of the railway.

6.2.5. Sabadell

There is yet a last project on the table, namely putting underground the last segment of the light railway FGC in the city of *Sabadell.* A 300m section was put underground in the year 2014 and proved to be a success (Figure XXIV). It helped relieve a space that was of vital importance in an area with high traffic. The railway cut through the grid street layout thereby disrupting accessibility. The remaining above-ground section is just 300m long, which is the distance between two crossing motorized traffic crossing points, so the enforced detour is not long at all. There is a wide pedestrian underpass halfway, which means both sides are well connected. Still, residents want such railway section to be put underground, as can be read in Figure XXV, which would mean redesigning a roundabout and underpass at the end of the section.

Figure XXIV: The 300m of FGC light railway running above ground in Sabadell.

Figure XXV: End of the recently covered railway. Note the tag on the wall demanding that the remaining stretch is put underground.

While the project would likely be beneficial to the community and complete the missing part of the grid layout, it is fair to say that the likely expenditure is not quite worth the little change this project would mean, and sounds more like a whim of the residents than anything else.

In the following table, the five locations where the railway is planned to be put underground are assigned a score for every criterion and subsequently, it is decided whether the interventions are justifiable and deemed a necessity.

city	**severe barrier effect**	**population density**	**No feasible alternatives**	**technical feasibility**	**justifiable?**
Montcada	✓	✓ (very high)	✓	✗	✓
Sant Feliu de Llobregat	✗	✓ (high)	✓	✓	✓
Hospitalet	✓	✓ (very high)	✓	✗	✓
Granollers	✗	✓ (high)	✗	✓	✗
Sabadell-FGC	✗	✗ (medium)	✓	✓	✗

6.3. Possible modifications- thorough analysis

There is a number of cities in Catalonia which do not experience such a severe barrier effect as some of the cities in the previous table, which is the reason why there are no plans to modify the course of the railway at least in the near future as they are not deemed a priority. Nevertheless, residents certainly have a wish to do so. Putting the railway underground might prove very beneficial to these major cities, to relieve space to strengthen the street network and in turn improve mobility and accessibility. Let us assess every particular situation in order to decide whether the course of the railway should be modified. This recommendation will consider the benefits that could be obtained with such changes and relate them to the estimated investment sum, to make an objective assessment.

6.3.1. Lleida

This city had the railway covered along most of the stretch running through the city somewhere in the late twentieth century, with another 500m stretch just north of the railway station covered upon arrival of the high speed rail to the city in the early 2000s (Figure XXVI). The approach this city took is nevertheless curious, since there was no real necessity to cover the railway, as there was barely any barrier effect at the time, as the area along the railway was still undeveloped, which means there was enough room on both sides of the railway to build wide enough streets. It was decided to cover the railway instead and build an avenue above it. This very avenue has proven to act as a major east-west backbone in the city. This is an example of railway that might not have been necessary to put underground yet the outcome has been so positive that it is hard to say it was not the right thing to do. From this, we can learn that we should not automatically rule out projects just because they are not “necessary”. It is not easy to say whether the railway in *Lleida* was worth covering, comparing the benefits obtained and investment then made, yet it is safe to say that the city has a very sound street layout that may not have been achieved otherwise and residents would not want to take it back for anything in the world.

Figure XXVI: Current railway layout in the city of Lleida.

The railway does however not run completely underground through the city. The stretch comprising the central station runs above ground, is 640m long and disrupts the street network perpendicular to the railway. This forces motorized traffic to detour around this area to reach a location across the railway. Pedestrian accessibility is, however remarkably good, as a footbridge, photographed in Figure XXVII, was cleverly built across the railway to enable access to the station from both sides, as suggested in section 5.2. To further improve pedestrian and bicycle accessibility, a wide underpass could be built roughly halfway between the footbridge and street *Av. Segre*, as there is enough room to host it.

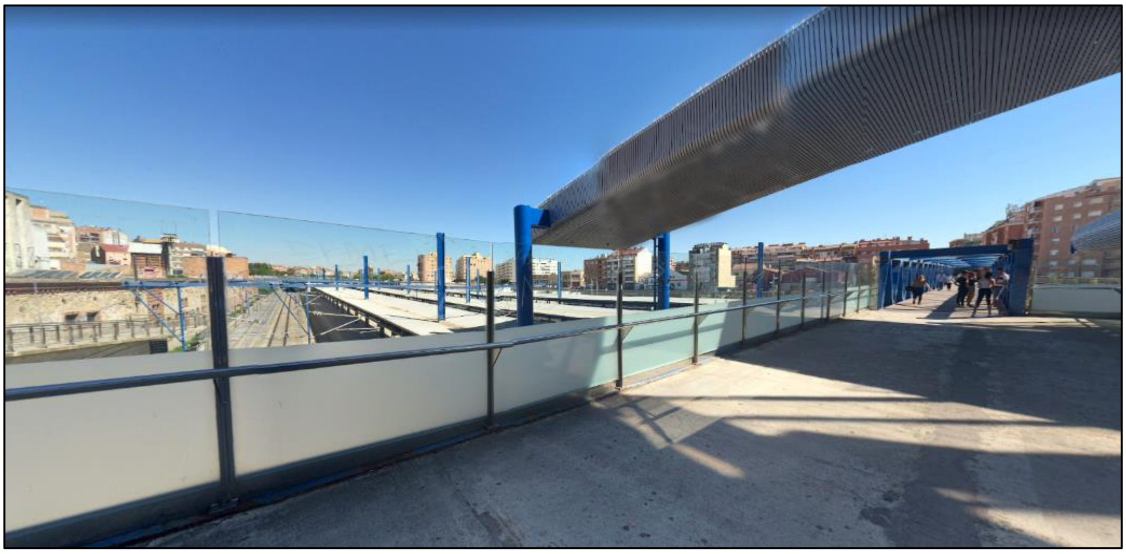

Figure XXVII: The footbridge over the railway in the central station.

Obviously, if such stretch of railway was covered, the street layout could be enhanced, as shown in Figure XXVIII, but this would not really be of much benefit to the city, as it would boost car use at the expense of cyclists and pedestrians. Gains in travel time would not be considerable either, and the current streets around the railway grounds seem to have smooth traffic flow. Noise is not a reason either, as buildings stand far from the railway and trains do not run fast within the concerned stretch, as it consists of a station. The high technical difficulty definitively rules out the possibility of modifying the level of the railway, as such action would mean the river just south of the city could not be spanned.

Figure XXVIII: The two new streets that could be opened if the railway was put underground. This new layout would result in a mere minute of time saving compared to the current layout. Note the bridge over the river on the bottom left; this bridge has an already very small clearance, which means it is not possible to lower it.

To better enhance the surroundings of the railway, the rail authority *Adif* could give up the adjacent grounds, which are currently dysfunctional, as seen in Figure XXIX and take up a considerable amount of space; and turn them into a park.

Figure XXIX: End of the underground stretch, just at the entrance of the station. Note the desolate area on the left, belonging to the rail authority; which could be refurbished.

The westernmost stretch of railway running above ground in a trench, shown in Figure XXX, seems to be well integrated within the surroundings; as the street layout has been developed in such a way that the railway does not cause barrier effect and is not necessary to cover. Covering such stretch of railway with the purpose of creating a road above it would result in the prolongation of the avenue that currently runs above the railway. Yet, because two wide roads already run almost parallel to it, a third road would be redundant, and it would lead nowhere, as the land southwest of Figure XXX is non developable and used for agriculture.

The southernmost stretch of railway, shown in Figure XXXI, also running in a trench, runs across a, as of 2018, yet undeveloped area, in the district *La Bordeta*, with no buildings but already present streets. If buildings are ever raised in such area, they should not stand too close to the railway. The adjacent land should be kept as green area to act as a buffer, to ensure nobody demands to cover the railway in the future. The street layout, not yet fully materialized, was planned in such a way that the railway is not necessary to cover and poses just as much (or little) impact as any other linear infrastructure element, such as a highway. If the railway was covered, a radial road could be built above it, running from the city centre to the outer ring road, providing a direct entrance and exit to the city. Yet, this road is not necessary, at least for the current size of the city, as Lleida already has seven such radial roads. It sure would lead to a better utilization of space, yet land value is not particularly high in this particular location to justify such approach, as there is no agricultural land, but empty, barren land; which means a road could be built right beside the railway, if such course is deemed optimal for one.

Figure XXX: The westernmost stretch of railway. Note how wide streets run parallel to the railway and are joined by a nearly flat overpass. This is an example of a street layout that integrates the railway very well and gives no reason to cover the latter.

Figure XXXI: The southernmost stretch of railway. Note how the recently laid out streets could be connected to the rest of the network (in grey). As long as houses are not built too close to the railway, the railway is bound to fit perfectly well without causing any nuisance.

In short, the course of the railway through the city of *Lleida* does **not** need any modifications at all: the above-ground stretch seems to be remarkably well integrated, and the underground stretch serves as an example of the very positive outcome that railway integration projects can have in a city.

6.3.2. Tarragona

This port city in the south of Catalonia is separated from the waterfront by the railway (Figure XXXII). This waterfront consists, in the northern stretch, of a promenade, a two-way road and the beach; and in the southern stretch, of port facilities, the port itself, and a small neighbourhood of 1100 inhabitants. The railway, just like in many other cities where it runs above ground along the coast, is perceived as a barrier. Yet the barrier effect, as we know it, is just not there. It is rather attributable to the aesthetics and functionality of the space. It is not difficult to understand why residents would rather the railway to run underground and have the relieved space turned into a wide promenade.

Figure XXXII: Current railway layout in the city of Tarragona.

As mentioned, because the sea side of the railway only consists of port facilities and leisure buildings, there is no barrier effect as we know it. The neighbourhood *El Serrallo* does lie on the seaside of the tracks, yet it is reasonably well communicated with the rest of the city, with two underpasses at each end, 350m from each other. The easternmost overpass, photographed in Figure XXXIII, is however a bit too narrow for the amount of people and vehicles that use it. It would be wise to consider renewing such overpass. Another option could be building a new underpass at one of the several streets that meet the railway in the form of a dead end. Since the railway runs on an embankment, as shown in Figure XXXIV, a street-level underpass for pedestrians/cyclists is very feasible to build.

Figure XXXIII: One of the underpasses connecting El Serrallo with the rest of the city. Note how narrow both sidewalks and road are. If some tracks were removed above, a better underpass could be built, thereby increasing the height clearance as well.

Figure XXXIV: One of the streets that could be prolonged over to the other side of the railway by means of a street level underpass.

There are numerous projects on the table to put the railway underground along a certain stretch. Most of them, however, plan to do so along the northern stretch, which as previously mentioned, does not pose any barrier effect. This may come down to the presence of a river just at the end of the southern stretch, over which the railway already runs at low height. Lowering the level of the tracks would mean this river can no longer be spanned, which means deep tunnelling would have to be used instead of cut and cover. The presence of branch lines that feed the port is also a constraint. If the railway is put underground, those branch lines would be cut off and freight trains would no longer be able to reach the port. These are likely the reasons why most proposed projects consider burying the northern stretch; yet if a stretch of railway is justifiable to put underground, that is the southern stretch. This is not only because of the previously mentioned community severance, but also because of the number of households affected by noise. The latter is almost three times larger in the southern stretch, as shown in Figure XXXV; and this difference is further pronounced by the fact that trains run fast in the southern stretch while the northern stretch comprises the railway station, which is much less noisy.

Figure XXXV: Northern and southern stretch of the railway. Note in red the number of households affected by noise is not high at 950. Note the location of the former level crossing.

Let us imagine, nevertheless, what the relieved space would look like and how it could be urbanized. Figures XXXVII and XXXVIII show the hypothetical new street layout in the northern and southern stretch, respectively. In the former, there seems to be barely any change, as almost the entire space that the railway used to take up is devoted to pedestrians. The road that currently runs along the beach would remain unchanged, as would the existing overpass at the north end of the beach. The only observable change is the new crossing point at the location of the former railway station. The apparent lack of change between current and envisaged scenario is due to the relief along the railway. Figure XXXVI shows how streets and buildings along the railway, from the northernmost end all the way down to the railway station, sit on a hill; at a much higher level than the tracks. This means that if the space that the railway takes up along such stretch is relieved, there is not much difference other than better aesthetics of the waterfront. The newly introduced crossing point, located at the point where the terrain flattens out, would be of great utility to provide better accessibility between waterfront and city centre. Within the current layout, there are only two crossing points for motorized traffic, located some 1800m apart. While the road along the beach and port is not very busy, it might still have to be used by people working in the port facilities and nearby businesses. A distance of 1800m without any crossing points is certainly long, yet if we consider that the municipality closed off the existing level crossing 300m west of the station, which used to allow motorized traffic across the railway; to turn it into a pedestrian underpass, we may realize that the strategy of the municipality is to reduce motorized traffic both in the city centre and the waterfront. Keeping a low number of motorized traffic crossing points may effectively deter people to drive to the waterfront and may choose to walk instead, thereby reducing congestion, noise and pollution in the city centre.

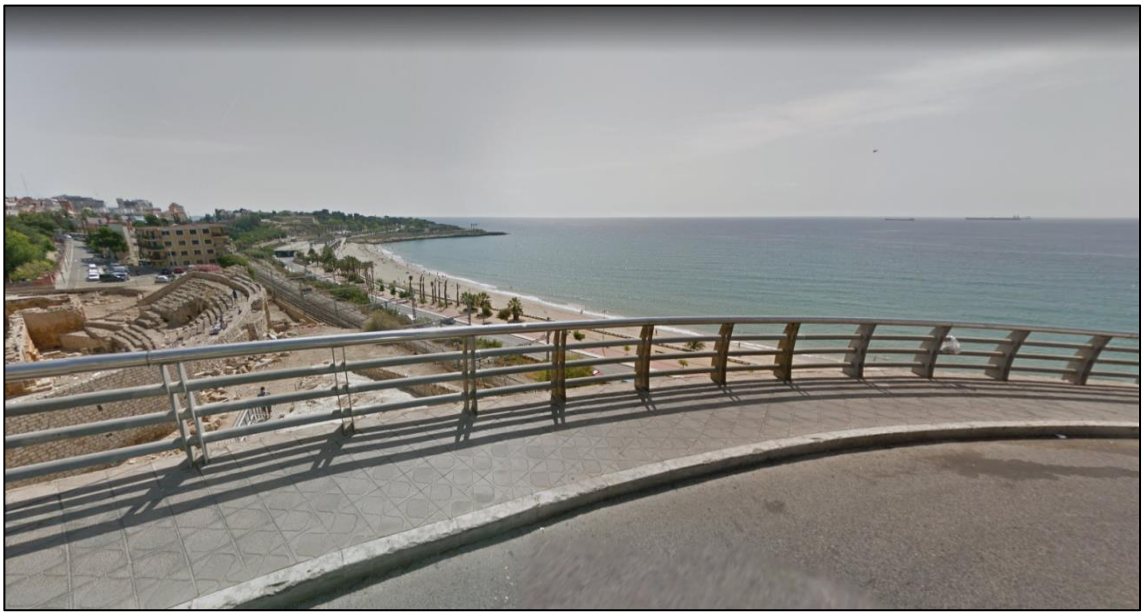

Figure XXXVI: The railway runs at a much lower level than the surroundings, which means the railway does not pose any barrier effect whatsoever, at least in this particular stretch.

All these factors make one think that the new street layout that could be achieved on the space that the railway used to occupy is not really of interest or beneficial to the community. Nevertheless, the relieved space could be urbanized as follows: a roundabout on the location of the former level crossing and current pedestrian underpass, in which the road along the waterfront would merge with the road feeding the port as well as enabling access to the inner city. The current street that runs in front of the first row of residential buildings would be widened, thereby becoming a two-way street and thereby complementing the existing road along the pier. The remaining space would consist of a green area, devoted to pedestrians. Conversely, the space could be developed for real estate. The location, just a hundred metres from the sea, what is more, with no railway in sight, means such land has an inherent high property value. It may attract the interest of investors. This might thus help cover the investment cost, yet not completely. In any case, this should never be the reason for putting the railway underground, just an option to fund the project. The envisaged layout would thus likely mean the appearance of two motorized traffic crossing points. This greater accessibility might attract more cars, something which is apparently not of interest to the municipality. Other than that, the street layout suffers minor changes. Now, unlike the northern stretch, the disappearance of the railway underground in the southern stretch would strengthen the pedestrian network, though not remarkably, as more cars on the streets may pose just as much barrier effect as the railway did. Yet again, it seems that the major gain here is the better aesthetics of a green area as compared to a rail yard. Furthermore, the southern stretch is not even thought of being put underground, for its incompatibility with the branch lines feeding the port, which definitively rules out this option.

Figure XXXVII: envisaged street layout if the northern stretch of railway disappears underground. Note one of the two current crossing points in black.

Figure XXVIII: envisaged street layout if the southern stretch of railway disappears underground. Note one of the two current crossing points in black.

Having thoroughly analysed the situation, everything seems to indicate that people and institutions that support projects to put the railway underground most likely appeal to the attractiveness that such projects might bring to the city and its waterfront, with the impact this may have on tourism, property value, investment, etc. The waterfront area may very well become more functional, mobility will likely improve, yet further than that there are no reasons to justify giving the area such a radical makeover. A much wiser option consists of the application of some measures that may prove much more beneficial than putting the railway underground. In this particular case, there is a lot of room for this kind of measures.

First of all, if all the projects to put the railway underground aim to relieve the space that the railway takes up, it is not understood why there is so much space within the railway facilities, that is clearly unused or unnecessary. The southern stretch of the railway within the city comprises a rail yard, which is more derelict than anything else. Rail yards do not belong in cities where space is scarce, let alone if they are rather unused. There is already a large rail yard some two kilometres out of the city that may also be used as depot. Figure XXXIX shows how deplorable the site looks. The railway authority should give up at least a 50m wide strip of their facilities, comprising the rail yard and several derelict buildings that most likely no longer serve their purpose. This would allow the currently very narrow street parallel to the first row of buildings to be widened, thereby even becoming a two-way street. The rest of the space could be converted into a green area and serve as a promenade for pedestrians. An underpass would then give continuity to this promenade by allowing access to the pier across the railway. This is depicted in Figure XL.

Figure XXXIX: A tall fence separates a seemingly derelict rail yard from a narrow one-way street. This much space devoted to rail facilities, which are also unused, is just not acceptable.

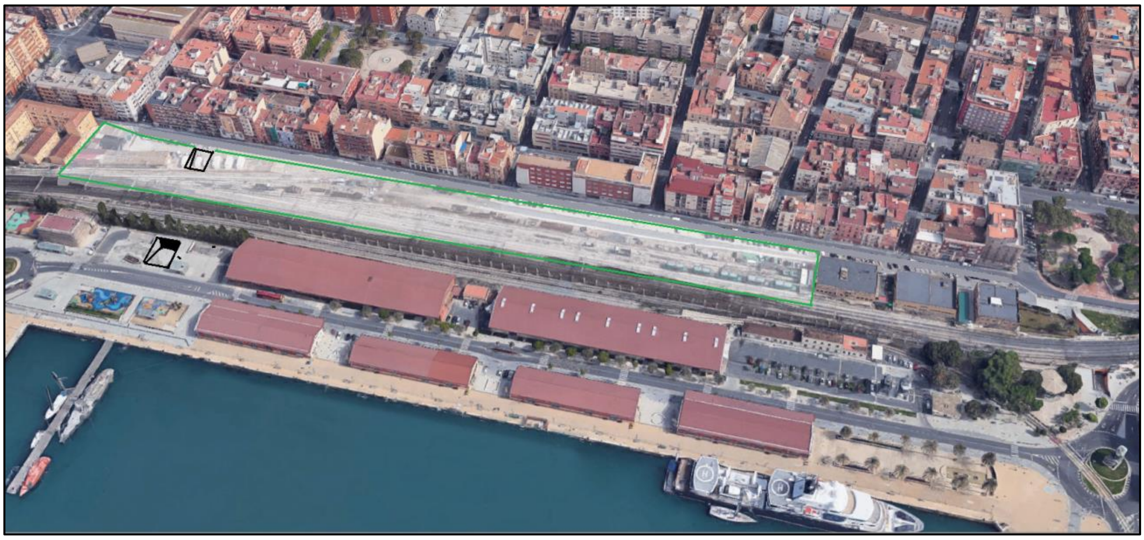

Figure XL: A better option to reduce the impact of the railway: dismantling the rail yard thereby reducing the width of the railway to four parallel tracks and relieving 1,8ha for pedestrian use.

The railway station likewise takes up excessive space. The main line spreads out into no fewer than eleven tracks (see Figure XLI). Seven of those are platforms, the rest serve as depot. Considering that the number of passenger trains running on those tracks is not too large and all of them stop, and the number of freight trains has dramatically decreased with the high speed rail line having absorbed most of the traffic, it is safe to say that such many tracks are in fact unnecessary. A reasonable number is six tracks, and while it may limit the use of the station as a depot, is definitely better than if the tracks were to be put underground. In such case, the likely number of tracks would not be larger than four.

Figure XLI: The number of tracks of the rail station of Tarragona seems to be excessive.

If the outermost four tracks were removed and the rail authority gave up the space to the municipality, the currently missing promenade could become a reality, thereby giving the waterfront the so desired makeover. This could be further complemented by the construction of a footbridge, already approved; and a wide pedestrian/bicycle underpass, the latter connecting the beach with the station, which are currently isolated from each other (Figure XLII).

Figure XLII: A better option to reduce the impact of the railway: removing five of the eleven tracks that the station currently boasts to relieve an area of little under 1ha. Note the underpass right under the station and the footbridge (due to be constructed) connecting the upper city with the waterfront.

To sum up, the situation of the railway in *Tarragona* is such that there is a lot of room for measures to mitigate its presence. We should **not** even think of taking such a radical step as putting the railway underground when there is a lot to be fixed above ground. The alternatives proposed in this section are enough to think that the railway can coexist with the city; it just needs a good integration, something which is definitely missing in *Tarragona*. Supporters of the most radical option, putting the railway underground, should see that on top of not being of much benefit to the city, what could be achieved with such action is not much different to what railway integration measures could deliver.

6.3.3. Reus

The railway layout in this city was cleverly designed such that it bypassed the city centre through the outskirts, unlike in most other cities in Catalonia. The urban growth spurt that took place at the beginning of this century; however, resulted in residential areas being built beyond the railway, which means parts of the city lie now on both sides of the tracks, as can be seen in Figure XLIII. The two railways that merge some hundred meters west of the central station do not see much traffic and thus pose barely any nuisance, which means modifications might only be justifiable on the busier line, running from the south up to the central station.

Figure XLIII: Current railway layout in the city of Reus.

The railway poses barely any barrier effect, as the few residential areas it separates are well connected by means of numerous over- and underpasses. Despite running mostly at ground level, the railway seems to be well integrated within the surroundings, with vegetation mitigating both noise and visual impact along its course, as shown in Figure XLIV. Despite the great length of the stretch that runs through the city, 6 kilometres, the total number of households affected by noise and visual quality is rather small, at roughly 1250.

In spite of the inner city having a very tight street layout, common to most cities in Catalonia, the outer city, developed from the 1990s, boasts a very strong street layout, with many four-lane avenues acting as transversal backbones of the city. Radially, a large number of avenues link the city centre with the two nearby highways. They all appear to successfully sustain the traffic, with no congestion observed. It is easy to understand why putting the railway underground to convert the relieved space into a ring road is a ridiculous idea. It may very well result in a better utilization of space, as it was the case in *Lleida*; yet this is only reasonable when there is a clear lack of space in an area with high land value. In the particular case of the city of Reus, there is already a ring road running through the outer city. Another ring road that runs a couple of hundred further is completely unnecessary, especially if it does not run through a residential area. The idea of putting the railway underground along its entire stretch is then ruled out. Let us have a look at some particular segments.

Figure XLIV: There appears to be a good integration of the railway along its southern stretch.

The southernmost stretch of railway, which separates two residential areas, is shown in Figure XLV. There is an extraordinarily large number of crossing points, namely two four lane avenues, one road and three pedestrian underpasses, all within a 600m long stretch. In the hypothetical case the railway disappeared underground, a road would likely be built connecting the two avenues by means of roundabouts. This would also mean rebuilding over one kilometre of road that currently sits on an embankment. This connection is currently not there, yet there is a reason for this. The two avenues are meant to be direct entrances/exits to the city, which means there should be barely any vehicles moving between them. As seen in Figure XLIV, this seems to be a very quiet area, in harmony with the railway, and the presence of a road would most likely be repudiated by residents. Besides, if such connection was desired, there is enough room to implement it a couple of hundred metres further south. Moving on further south, we come across an already urbanized yet still undeveloped area. A two-way road runs parallel to the railway, which means it makes no sense to build another road above it. If anything, roads may be built across the railway if necessary.

Moving over to the northern stretch of railway, which contains the station, we can quickly point out the following: the station and related facilities take up a large area, and buildings stand far enough from the railway, except for a row of some fifteen attached houses that were built directly adjacent to the tracks. Two wide avenues run along the railway on both sides, making for a very resilient street layout.

Figure XLV: The southern stretch of railway, running through a residential area. Note the number of crossing points in yellow (pedestrians) and red (vehicles). The two avenues running perpendicular to the railway pose far more barrier effect than the latter.

Figure XLVI illustrates how the relieved space could be urbanized in case the railway was put underground. The central avenue would be extended at the location of the current station building to join the avenue across the railway. The space the railway used to take up would most likely be devoted for pedestrian use, in the form of a green area, and not of a road, because of the lower level of the railway with respect to the surroundings and the fact that two avenues already run parallel to it, which would make a third one redundant. A new street could be opened in case some of the area was developed for real estate, but would, in any case cover the same stretch as the already existing road. Another road could be created across the railway, roughly one kilometre down of the central station, thereby giving continuity to a current dead-end by connecting it to the main avenue and thus creating a second entrance to the outermost residential district, see the rightmost part of Figure XLVI. This last road could in fact be perfectly built under the current railway layout, by means of an underpass, as there is enough room for it. In short, the benefits obtained from putting the railway underground do not seem to go any further than the extension of the avenue running north-south, some space relieved for real estate development and the better visual quality and less noise of some 500 households.

Now this does not mean that prolonging avenue *Passeig de Sunyer* towards the north, thereby connecting the northern part of the city, is a bad idea. The thing is that there is enough space to build this road as an underpass, and if it has not ever been considered, it may mean it is not of interest to the municipality to create such road, as can also be read from its urban plan *POUM*. From this very document, we learn that the municipality plans to dismantle the current railway and build it in the outskirts instead. These plans might, however be rather far-fetched as they were conceived at the beginning of the economic downturn, yet they are still official. Either way, the future of the current railway is uncertain, which means considering plans to put it underground is not a safe bet. Furthermore, if such project was brought forward, no more than two tracks would likely be built, which might result in a bottleneck; despite Reus not seeing so many passenger trains, freight trains are a very common sight, and side tracks are necessary for them to ride past the station. In short, the northern stretch of railway is the only one that might pose enough of a nuisance to consider modifications. Nevertheless, all the discussed factors seem to point to the railway remaining above ground in this stretch as well.

Figure XLVI: How the space relieved from the northern stretch of railway could be urbanized. Note: the road on the very left is already present, just as an underpass.

Saying that it is not reasonable to put the railway underground does not mean that the situation of the railway is currently satisfactory. Aerial images certainly do not quite reflect the reality. On the ground, we can see that there is something wrong with this northern stretch of railway. There is indeed a problem with the railway, but it is not the space it takes up, the noise it makes or its mere presence, but rather its integration within the surroundings. Once again, we see the same situation as in *Tarragona*. As can be seen in Figure XLVII, the area adjacent to the station consists of nothing but abandoned facilities of a former rail yard. The presence of such a run-down place, enclosed by a tall wall, multiplies the barrier effect. If that plot belongs to the rail authority, they should give it up and have it refurbished as a green area or whatever the municipality might want to use it for. In any case, a wide underpass should be built across the railway, preferably for pedestrians and cyclists, although it could also be for motorized traffic if the municipality so wishes, as there is enough room. This underpass is necessary to provide the necessary accessibility between the newly developed north part of the city and the railway station as well as the rest of the city, which are currently cut off, as shown in Figure XLVIII.

Figure XLVII: The old rail yard facilities now decayed and apparently abandoned. We cannot even afford to talk about putting the railway underground without sorting out sites such as this one first.

Figure XLVIII: How an underpass could provide the same accessibility as a scenario without the above-ground railway. Note the sheer size of the former rail yard, 4 ha.

In conclusion, the railway in the city of *Reus* seems to be pretty well integrated except in the station and immediate sections. This area appears to be neglected by the railway authority. After envisaging what the benefits could be, namely not many, it is fair to say that putting the railway underground is not the approach to take. Less costly and radical measures such as renewing facilities and rethinking the use of space have a much better outcome. Those that endorse the idea of dismantling the railway to build it in the outskirts of the city should come down to earth and see that the current course barely poses any nuisance and there is a wide range of possibilities for mitigation measures.

6.3.4. Girona

The railway runs right through this city of 100000 inhabitants. It used to do so at ground level, but because of the enormous barrier disruption it caused to the city, as this grew in population and thus vehicles, it was decided to elevate it on a four metre tall viaduct along a two kilometre stretch corresponding to the most densely populated area of the city. This viaduct means the physical barrier effect is nearly zero, at least for pedestrians and cyclists; as some underpasses have a limited height clearance, which may impede the passage of lorries. So far so good; however, upon seeing the city layout, in Figure XLIX, we can quickly recognize typical features of cities in Catalonia, as described in section 5.2, which are usually not compatible with above-ground railways. First, we notice a high population density, namely 19000p/sqkm. Second, the street layout is irregular and rather messy, especially around the inner city (see top of Figure XLIX). Lastly, in the latter stretch buildings stand very close to the railway. In section 5.2, we discussed the conditions for an elevated railway to be in harmony with the surroundings. One of those conditions was the existence of a wide strip on both sides, used as a road, green area or similar yet not as a residential area; because of the noise, shading and visual impact elevated railways have. Particularly along the northern stretch of railway it is clear that this strip is completely missing. This situation clearly improves as we move south. Despite the gap between buildings and railway not being optimally wide either, we see that more recent buildings do not stand as close to the railway when compared to the older, more tightly packed together buildings along the northern stretch. The total number of households affected by noise is roughly 2300. This is a large number, which may very well be reason enough to put the railway underground, yet most of those households seem to be located in the northern part of the city. This seems to be, by far, the most problematic area. If we take a closer look, namely from the ground, we see how some buildings stand horrendously close to the viaduct, thereby their dwellers being exposed to the full estimated 85dB of noise at 15m shown in Figure I. Considering that trains run roughly every fifteen minutes and freight traffic is considerable, the noise impact is large. On top of the noise, such proximity makes vibrations noticeable in buildings. We might ask ourselves why, knowing that these issues were bound to occur, the railway was not put underground in the first place instead of elevating it on a viaduct. The reason might have very well been the presence of river *Onyar*, an obstacle that is most easily sorted with a bridge. Nevertheless, if the decision-making authority had given some thought to the likely population boom *Girona* might experience, they would have chosen to bury the railway, which would have likely proved the more cost-effective option.

Figure XLIX: Current railway layout in the city of Girona. Note the number of households located within a 100m wide strip along the railway; most of them are located along the northernmost stretch of railway.

The noise and visual impact is; however not the only issue arising from the presence of the railway. As mentioned before, and unlike in previous cases such as *Lleida* and *Reus*, *Girona* does not have a very strong street layout. Congestion is not uncommon in the city, especially on *Carrer Barcelona* (Figure L), one of only two streets to run north-south continuously through the city, as the other parallel streets are all interrupted at a certain point. This two-way, four-lane street acts as a backbone of the city, handling the great majority of vehicles entering or leaving the city, which in the case of non-residents, approaches the entirety of vehicles. This street seems to have become a little too small to handle the increasingly high number of vehicles entering and leaving the city. The street becomes narrower towards the north end, thereby causing a sort of bottleneck. The railway runs parallel to this street some 150m to the west, also along a continuous corridor.

There seem to be, thus enough reasons to justify a modification of the railway. The city council of *Girona* has repeatedly shown its support to put the tracks underground, yet the claims have dwindled in the past years due to the lack of interest from central and regional government as well as the lack of funds. This is the main problem that the undertaking faces, the willingness to fund such an expensive project.

Figure L: View of Carrer Barcelona, the backbone of the city.

Unlike railways that run at ground level and are to be put underground, shifting the tracks from a viaduct to underground is substantially more costly, because of demolition costs and the fact that the length to be modified will certainly be longer than intended, because of the high level difference between former and projected railway. In the present case, there is a much more challenging element. A river would have to be sorted, as shown in Figure LI, which means the railway must be buried at a greater depth than usually. This depth is large enough that the cut and cover method is not applicable and a tunnel would have to be bored instead. Because the latter is more expensive than the former, costs increase dramatically.

Figure LI: The railway bridge over river Onyar. The water depth is around a metre.

Let us now see how the street layout would end up looking if the railway was built underground and the viaduct was demolished. Despite the stretch on viaduct being the most conflictive, the southern stretch on embankment and ground level would have to be shifted underground as well, because of the depth of the tunnel. As mentioned, the railway runs currently along one of the three continuous north-south corridors of the city. Along some stretches, streets run right beside the railway, though their width varies depending on how far apart buildings stand; yet these streets are neither continuous nor straight, as they are interrupted at some point. The main change in the street layout to be achieved by putting the railway underground is the relief of this second corridor to take some of the traffic off the neighbouring *carrer Barcelona*. The use of the relieved space will eventually be down to the municipality; nevertheless, we may propose a new layout. Currently, *carrer Barcelona* is a two-way street along its total reach; the proposal consists of the latter taking the northbound traffic and the railway corridor taking the southbound traffic, on a new continuous street. The traffic flow in north-south (and vice-versa) direction is expected to improve with this measure, as the current layout makes *carrer Barcelona* a quite congested and noisy street, which should not convey pretty much all vehicles entering and leaving the city. The number of lanes may be cut down from four to three on each road, and this space may be used to extend sidewalks and introduce a bicycle lane. Four one-way lanes are likely to have a larger impact in noise and vehicle speeds and might make the situation worse. Let us split the railway stretch to be put underground into four segments and analyse the envisaged street layout.

Starting from the south, Figure LII shows the stretch of railway from the tunnel entrance up to *carrer Antoni Gaudi*. Along this stretch, the railway runs on an embankment, with increasing height as we move north, to rise from ground level to viaduct level while limiting the slope. A two-way road runs along the railway from the top to halfway of Figure LII before heading west. Further south, the railway winds its way through industrial buildings, which means that the space to be relieved cannot be used for much more than enlarging plots of land. Optimally, in the envisaged situation, the railway should run underground until the beginning of the industrial area, as shown in Figure LII; yet the exact location is a priori not known as the slope constraint may eventually determine the tunnel entrance to be further south. The governing height would be the height of the viaduct as well as the height of the underpass of *carrer Marti Sureda* (see Figure LII, the east-west street with the roundabout), which would have its level raised a couple of metres.

There are two underpasses within this 700m long stretch, so the barrier effect is present. There are currently no crossing points south of the roundabout, in Figure LII, which results in a lack of accessibility between two residential areas. The new layout would be as follows: *Carrer Barcelona* would remain a two-way street until the junction with *Carrer Marti Sureda*. From there to the north, as the street enters a more densely populated area, it would only convey northbound traffic. It proved very tricky to find an appropriate street arrangement within the railway corridor, because of the current layout, which is tailored to the course of the railway.

Figure LII: The southernmost stretch of railway to be built underground. Note the arrows indicating the traffic direction. The land enclosed in brown is may be built-up and the land enclosed in green may be kept as a green area.

The chosen option would entail joining the east-west avenue *Carrer Marti Sureda*, the south-north avenue *Carrer de Santa Coloma* and the southbound street *Carrer Oviedo* in a roundabout. Currently, *Carrer Oviedo* crosses over *Carrer Marti Sureda* on a bridge, as does the railway (see Figure LIII). The underpass has a height clearance of 4,2m; which may be just too short for big lorries, and due to its very low elevation as compared to the surroundings, it usually floods during heavy rain episodes. The roundabout would lie at an intermediate height. This would likely reduce the depth constraint of the railway, and in turn the length of the underground stretch. *Carrer Oviedo*, a two-lane street running parallel to the railway would become part of the continuous southbound street, and could be enhanced to a three-lane street. The space relieved by the railway would be either used as green area or for real estate development. South of the roundabout, two currently dead end streets would be joined, thereby providing a more direct access across the railway corridor. The latter street and the roundabout would convey all southbound traffic into *Carrer Barcelona.*

Figure LIII: The underpass under the railway and road bridges on Carrer Marti Sureda. Note the height clearance.

Heading north, the next stretch is shown in Figure LIV. At the location of the underpass of *Carrer Cassia Costal*, the railway shifts from embankment onto viaduct, which means there is no barrier effect to the north of this point. If the viaduct was demolished, the new street layout would look as follows: (from south to north), the new southbound street would run on the existing two-lane road that runs parallel to the viaduct, although it may be enhanced to a three lane road; until *Passeig Olot,* from where no road currently runs along the viaduct. From this point, a new road is to be built directly above the railway. The four intersections within this stretch would not change.

Figure LIV: Second stretch of railway. Note that Carrer Barcelona, 150m to the right of the railway would become a one-way street along this entire stretch.

Moving further north, we enter the most problematic stretch, the one that brings up the idea of modifying the course of the railway in the first place. Within this stretch, while there is no barrier effect, the street layout is severely constrained, as the already narrow streets are further narrowed by the presence of the railway viaduct. In the current layout, streets do run along the railway corridor, although not continuously; yet they are very narrow, as shown in Figure LVI. The new layout, shown in Figure LV, would look as follows: (from south to north) the new southbound street would run past the location of the current and future station. The current railway station building is very wide (underlies five rail tracks) and hence stands in the way of the envisaged southbound street. A solution would be to either reduce the width of the building to make room for the street, or build a new, small station building next to the high speed rail building and demolish the existing one. The three intersections located north of the station, which are currently rather messy, because of the space constraint imposed by the viaduct pillars; would be rearranged into tidier layouts. The narrowest section within the railway corridor, a 200m segment, part of which is shown in Figure LVI, would see the most radical change. There is currently so little room between viaduct and buildings that there is barely sidewalk and the remaining space is used as a car park. This lack of space results in a rather neglected street, something that should change if the viaduct disappears. *Carrer Barcelona*, the main northbound street, eventually meets the new southbound street; from where two two-way streets run north. These two streets would not see any change, not even the street running along the railway; as the viaduct is only two tracks wide in this section and buildings stand far enough from it to accommodate a wide carriageway on each side.

Figure LV: The stretch of railway between the station and river Onyar. The location of the station building is only indicative.

Figure LVI: One of the narrowest sections of the railway corridor. Note the nearly non-existent sidewalk, no wider than a curbstone.

Figure LVII shows the northernmost stretch of railway. The previously described street runs along the viaduct, before ending in a roundabout. Moving over to the other side of the river, the railway runs on a very tall embankment, rather resembling a wall, and does so all the way up to the very end of the city. This wall does; however, not pose any nuisance, as it stands back to back with the rear facades of buildings. If the railway was built underground, the viaduct up to the river would be demolished. The bridge may be left intact, as may the first segment of the tall embankment, from the bridge up to the location of Figure LVIII. The rest of the stretch on embankment would likely serve no purpose, as there is already a road running along it. The railway would likely only come out to the surface at the very end of the city because of the slope constraint. As shown in Figure LVII, there would be absolutely no change in the street layout within this entire stretch, despite being the most technically challenging and thus costly.

Putting the railway underground in *Girona* would thus prove beneficial to the city. On the one hand, a reduction in noise and visual impacts would increase the property price and quality of life of residents, yet only those within the penultimate stretch would really see a substantial difference. On the other hand, the street layout could become better and more resilient with the addition of another corridor to stop the full dependency on *carrer Barcelona* and make the latter safer and less noisy. The layout suggested in the previous section is however just an option to make the most of the relieved space. It could be left as it is with minor changes yet there would not be many benefits other than a reduction in noise for a certain number of residents and better aesthetics.

Figure LVII: The northernmost stretch of railway. Note the likely location of the tunnel entrance (on the left, in green). Note also that the underpasses and roundabout would not change at all.

Figure LVIII: The embankment/wall bearing the railway. Note how it takes up a space that buildings would otherwise, thereby posing no barrier effect.

Let us see whether these benefits are enough to justify the cost of the project. The project would involve the construction of a tunnel, approximately two kilometres of which deep bored and little over a kilometre trenched and covered; another kilometre of trenching to comply with slope requirements, the construction of an underground station and the demolition of the viaduct. This would amount to some 350M€, a very high cost for a project with zero financial revenue. It is more than obvious that the benefits previously listed, despite being difficult to value; do not outweigh the cost of the project. Despite the outcome of the project being positive for the city, the railway poses no severe problem other than the proximity to buildings along a 500m stretch. Along the rest of the railway the street layout could very well be improved, as suggested in the previous section, yet the current layout poses anything but a severe problem. The particular physical context does not allow for a partial modification but is rather an “either all or nothing” and obliges to modify over four kilometres of railway to solve an issue present along a 500m stretch. This makes the project very difficult to justify.

We should also discuss whether the situation is so bad in the first place. The integration of the viaduct within the 500m most affected stretch has greatly improved thanks to measures taken by the municipality. Figure LIX shows two of those integration measures. First, note how the ugly aesthetics of the viaduct are disguised by ivy. This may sound ridiculous, but it effectively alleviates the psychological component of the barrier effect. Second, note the utilization of the space under the viaduct. It used to be dysfunctional until a bike lane was cleverly installed. These measures may not make up for the noise but do certainly contribute to mitigate the impact in a physical context where there is little room for alternatives. On top of that, the railway, especially the viaduct and bridge over *river Onyar* has become an iconic element of the city, and most people would actually rather leave it as it is than have it built underground.

Figure LIX: Measures to mitigate the presence of the viaduct. There is less psychological barrier effect with a green viaduct than with a viaduct with spalled concrete and exposed rebar.

In short, the city of *Girona* would certainly be better off if the railway ran underground, yet the little severity of the current railway impact, especially when compared to the project costs; suggests that putting the railway underground in *Girona* is **not** really desirable nor justifiable and absolutely not a priority project.

6.3.5. Figueres

The conventional railway runs mostly on the edge of this city of 46000 inhabitants, as shown in Figure LX; yet there are two neighbourhoods of 2900 inhabitants that lie on the outer side of the tracks. The railway runs at ground level along the entire stretch through the city. Buildings stand very close to the tracks, especially those on the main streets; which results in the two crossing points that communicate both sides of the railway consisting of level crossings. Despite the physical barrier effect not appearing very severe on the map, as the stretch of railway that runs through the built-up area is 600m long; it is a different story on the ground. As shown in figure LXII, the isolation of the neighbourhood beyond the railway from the rest of the city has proven to have very negative consequences. The area beyond the railway has an abnormally high number of abandoned buildings and bricked up doors and windows. It definitely looks rather run-down, especially when compared to streets and buildings standing some feet across the railway. Despite the isolation only being partial, as there are two crossing points; the only drawback being some but little enforced detour; there must be a psychological barrier effect component that explains the condition of this part of the city, and the deterioration it has endured over time. Despite this neighbourhood showing clear signs of decay, some 750 people still live in it. This part of the city should not be left to deteriorate particularly because of its location on one of the main entrances/ exits of the city.

Figure LX: Current railway layout in the city of Figueres. Note the location of the four crossing points: the two motorized traffic passes in the outskirts, in red; and the two level crossings, within built-up areas.

Further east, the second neighbourhood, with some 2150 inhabitants, lies already isolated from the rest of the city; yet it still belongs to the latter. This neighbourhood is particularly vulnerable to segregation, as most residents live on low income with a large percentage of them are children. The presence of a barrier like the railway certainly does not help to encourage social cohesion. Both neighbourhoods lack every kind of public facilities so residents regularly travel across the tracks to the city centre, and most of them do so on foot. Even though the two level crossings are located such that people are not driven to cross the tracks recklessly at an intermediate location; something that happens in some previously discussed cities, the presence of the railway may very well make residents feel isolated from their own city.

Moving on to the noise impacts; Figure LXI shows that the number of households affected by noise is about 1400, which is considerably high, yet that would not justify a modification of the course of the railway by itself. Train frequencies lie around one train every fifteen minutes (either direction) on the stretch from the south up to the station and one train every half an hour on the stretch from the station to the north. Freight trains are regular users of this railway, and unlike passenger trains, also run at night, and thus cause more noise disturbance, which level crossing bells further increase. Noise is however not nearly the main issue that the railway poses in this city.

Once again we are dealing with a city with a very tight street layout. Population density is high and streets are narrow. There are very few exits/entrances to the city; in what could be considered a maze of layout. The east side of the city, bordered by the railway only has two exits/entrances: one at the very south and *Avinguda Vilallonga*. This avenue is the gateway to the city from the east. It is in fact the urban stretch of the road that links *Figueres* with *Roses*, *Empuriabrava* and many other locations, which are not only much frequented tourist attractions but also big population centres whose residents regularly visit *Figueres*. This road sees, thus a lot of traffic throughout the whole year. As it enters the urban area, the road, under the name *Avinguda Vilallonga,* becomes narrower and ends in the very city centre, at a real bottleneck. The fact that streets are so narrow in the inner city and there is a large amount of incoming vehicles means traffic flow is very bad. Since this is the only entrance/exit to the city from the east and unfamiliar drivers usually choose it over other routes; the result is not a surprise. Congestion happens on a daily basis throughout the year, and it worsens in summer when more people visit the city, coming mostly from the east. This road happens to be the main street that connects the two parts of the city across the railway, discussed previously, which means there is a level crossing. The presence of the latter, even if the barriers are only closed roughly every half an hour, further worsens the congestion. We are thus before a delicate situation: a congested street that also serves as the main route for pedestrians, plus a level crossing.

Figure LXI: The number of households affected by noise is shown within the yellow 100m wide strip. Note the location of the basic public facilities: hospitals, schools and city hall are all located on the larger part of the city, which means people living across the railway have to cross the latter regularly.

As far as the possibility of implementing alternatives or mitigation measures along the railway, there is not much that can be done. Replacing either of the two level crossings by under/overpasses is out of the question, as there is not enough space. Building another crossing point just south of the railway station is not possible either because of; yet again, limited space. There is certainly room for an underpass but it would have to be very narrow, which would not solve much. As shown in Figure LXII, the integration of the railway within the surroundings leaves much to be desired. A short fence is the only element separating streets and tracks. Planting trees or hedges to disguise the railway is only an option along a short stretch, because of the lack of space.

Unlike in previous examples such as *Tarragona* and *Reus*, the very poor integration of the railway is not down to the negligence of railway facilities; there is an abandoned depot building and tracks but far from residential areas; but is the result of the proximity of buildings to the railway. This, added to the poor street layout of the neighbourhood across the railway, which consists of the main road *Avinguda Vilallonga* and mainly narrow dead-end streets, is likely the reason behind the deterioration of this part of the city.

Figure LXII: Buildings of the neighbourhood east of the railway, on the left; and the rest of the city, on the right. See the run-down state of many of the buildings. Note also the poor integration of the railway and the dysfunctional nature of the adjacent land, used as nothing but car park.

It is not long before the idea of modifying the course of the railway comes to mind. The two options are elevating the tracks on a viaduct or putting them underground. Since, at first glance, there is no technical difficulty; the second option is clearly the more appropriate and probably also the more economical. The purpose of this undertaking is mainly to strengthen the severely fragile street layout of this part of the city in order to improve mobility in both this part and the city as a whole. This would likely result in the revival of the now decayed neighbourhood lying beyond the tracks, brought on by a much better cohesion of this currently outlying part of the city.

The local government of *Figueres* has shown its support for this undertaking, yet the project has never been conceived. Until very recently, the local government and urban planners had two options in mind to solve the same problem: putting the railway underground (over a yet undefined length), or dismantling the stretch of conventional railway that runs through the city and building a new railway bypass just north of the city. Even though the new layout, shown in Figure LXIV, would rely on six already existing kilometres of railway (branch line *Vilamalla-Vilafant* and high speed rail line) and mean that the high speed rail station would also serve as conventional station, some five kilometres of new railway would have to be built, including a tunnel. This option is, in the author's opinion, not appropriate; as it would result in severe disruption of fields and would prove very expensive. On top of that, the conventional railway station generates considerable economic activity in the east of the city, something that should be preserved. Putting the railway underground is a much more economical and reasonable option. As of April 2018, the local government seems to have finally taken a stance and advocate for the latter option over the former. *(ref.7)*

Figure LXIII: The level crossing on one of the main entrance/exit roads of Figueres. Note how congested the road gets even when the barriers are up.

The benefits of putting the railway underground are; however, not clear as water. The presence of the railway is indeed part of the problem, but a bigger part of it is actually down to the narrow nature of the streets in this city. As seen in Figure LXIII, not even main streets are wide enough. We have to be realistic about what can be achieved with a modification of the railway. When the latter is no longer there, whatever improvements are made on the street layout, they have to rely on existing streets, which prove to have a serious space constraint. Let us now see how the street layout could be improved in the space relieved by the railway:

The total length to be put in a trench and covered should result from a trade-off between the cost of this action and the additional benefits of doing so along a longer stretch. Since putting a stretch of railway underground implies lowering the tracks over a certain transition distance, along which the railway runs uncovered; it may be worth it to make the covered section a little longer, as long as there are no obstacles in the way that drive up the costs. If the municipality wished to extend the underground stretch in the future, it might very well prove more costly than if it is made somewhat longer from the very beginning.

Figure LXIV: Possible options to modify the course of the railway in Figueres. In orange, see the new stretch of railway to be constructed if the local government opts for dismantling the existing railway and building a bypass through the outskirts. The dashed line stands for the stretch in a tunnel and the solid line for the stretch running at grade. In red, see the stretch to be put underground. The four options are shown in distinct shades of red.

The location of the northern end of the stretch to be put underground depends on whether the road that would run above the railway is wished to be extended up to the first ring road, and connected to the latter. If this is not considered to be feasible or appropriate, the northern end would be located at the end of the residential area. On the southern end we may also contemplate two options. The first one consists of putting the railway underground up to the underpass of *Ronda Sud*, to create a better link between the latter and the road on the railway corridor, as well as relieving more space and reducing noise and visual impact for a greater number of residents. The second one consists of not deeming the benefits achieved with the first option worth the larger investment and therefore considering the underground stretch until a point some 200m south of the current railway station building, which would cover the most severely affected stretch and give the street layout a good enough makeover. These four options, depicted in Figure LXIV, can be combined into four different cases. In the following paragraphs, they will be discussed in order to find the most appropriate one.

Unlike in other cities previously addressed in the present thesis, such as *Reus* or *Lleida*; in the case of *Figueres* it would make sense to turn the railway corridor integrally into a street to act as innermost ring road (there are already two ring roads east of the city), as it would run some 600m from the second ring road at the farthest section, far enough in order not to be redundant. This two-way street would partly rely on existing roads, but most of it would run directly above the railway. As previously discussed, this street could run from the overpass in the north all the way to the underpass in the south, thereby acting as a full ring-road, or cover a shorter distance along the railway corridor. Let us consider the northern stretch of railway:

Figure LXV: The overpass of Cami Palol (part of the innermost of two ring roads east of the city). Note the four lanes of the road and the level difference with respect to the railway running underneath.

The northern stretch lies north of *Avinguda Vilallonga*. One of the options, shown in Figure LXVI, consists of putting the tracks underground up to the overpass of *Cami Palol* (see Figure LXV). This overpass and access slopes, 330m long, would need to be flattened out to allow for an intersection with the road running above the railway; the whole purpose of this option. This intersection would prove difficult to design, as a roundabout is out of the question because there are already two of them nearby. The four lanes of the existing road make it even more difficult to create a junction. The benefits this option would provide must clearly outweigh those of the alternative option, as the cost of the former would be much higher: a longer underground stretch of railway; the realignment of 330m of a relatively brand new road (from the year 2006), whose investment is light years from being paid off; and the creation of a junction that may not function properly.

Figure LXVI: The envisaged layout of the northern stretch if the railway is covered up to the ring road of Cami Palol. Orange arrows indicate the traffic direction.

The second option, less ambitious; yet at first glance more reasonable, consists of putting the railway underground up to the end of the residential area, roughly at the section where the railway course straightens out (moving north); some 300m before the overpass. In this case, as shown in Figure LXIX, the street running along the railway corridor would not see continuity to the north but come to a dead end. This stretch would; however, not consist of a new street but of an existing one that runs immediately adjacent to the railway. This street, shown in Figure LXVII, is the only access way to a group of twelve households and comes to a dead end. An option to give continuity to this street, which is largely unused; especially for its width, is extending it up to road N260, a major entrance/exit road to the city, which sees high traffic volumes and more often than not congestion. By means of a small roundabout, and an access way built on an existing dirt road, the two roads could be connected (dashed line in Figure LXVI), thereby achieving a similar result as the first option. This is however easier said than done, as several private plots lie in the way, which means we cannot rely on this connection, yet it is a possibility.

Both in the first and second option, the street along the railway corridor would run on the existing street up to the current northernmost level crossing. The land relieved above the railway would become a green area. Further south, first and second option being the same, the railway would run entirely underground, relieving space to redesign the street layout, which would look as follows:

In the current layout, south of the northernmost level crossing, it gets narrow; as shown in Figure LXVIII, the two-way street of Figure LXVII splits into two narrow one-way streets on each side of the railway. The idea is to merge these two streets into one, running directly above the railway. The sides would be devoted to pedestrians and cyclists.

Figure LXVII: The dead-end street that runs adjacent to the railway along the northernmost stretch. It does not see much traffic. The second option considers putting the tracks underground up to this very location.

Conversely, another option is that the two existing streets, to some extent widened, assume motorized traffic; and the middle strip is devoted to pedestrians. This might; however not make the street functional enough to attract traffic off *Avinguda Vilallonga* and other congested streets. The new two-way street would run up to the southernmost level crossing of *Avinguda Vilallonga*. This wide two-way street would act as a backbone, something which is completely missing in the current street layout. Two streets that run west-east (or vice-versa), almost perpendicular to the railway, which are currently cut short by the latter would be joined across the new backbone street, most likely by means of intersections of the type give way. These two narrow one-way streets (see Figure LXIX) come to a dead end on the east, as they are cut short by a 2,8ha private plot of land. Nevertheless, these streets would see most of their traffic to the west of the railway, as the stretch located east of the railway only runs past two blocks.

The new street along the railway corridor would thus greatly improve mobility in north-south direction. Yet, in east-west direction, *Avinguda Vilallonga* still conveys almost 100% of the traffic. It is not difficult to figure out what is the reason behind this: there is another street running east-west linking the city centre with the ring road across the railway (through the northernmost level crossing), namely, *Passeig de Vilatenim*. However, it has a limited accessibility: on the one hand, it is only accessible through one-way, very narrow streets; on the other hand, the street itself is narrow and only spreads out some 180m east of the level crossing.

Figure LXVIII: The point where the road of the previous figure spreads out into two narrow streets. Note the level crossing in the background.

Figure LXIX: The envisaged layout of the northern stretch if the railway is buried up to the end of the residential area. Dashed lines indicate possible but uncertain interventions.

Further east, the street is just as wide as *Avinguda Vilallonga*. The idea for the new layout is to exploit this street to take on some traffic off *Avinguda Vilallonga*. The existing surrounding narrow streets cannot be widened, yet the street running along the railway would provide very good accessibility to attract vehicles onto *Passeig de Vilatenim*. For this strategy to really be effective, the latter would need to be widened some two metres along a 120m stretch, shown in Figure LXX. The previously described plot of land is the reason behind this bottleneck, which means its feasibility is uncertain. This action is not a necessity but would be highly recommendable in order to make the most of the new street layout. Another possible strategy is the extension of one of the two previously discussed dead-end streets to connect it to another street some 100m east of the latter, but this seems rather unfeasible as this street would cut through the same private plot of land.

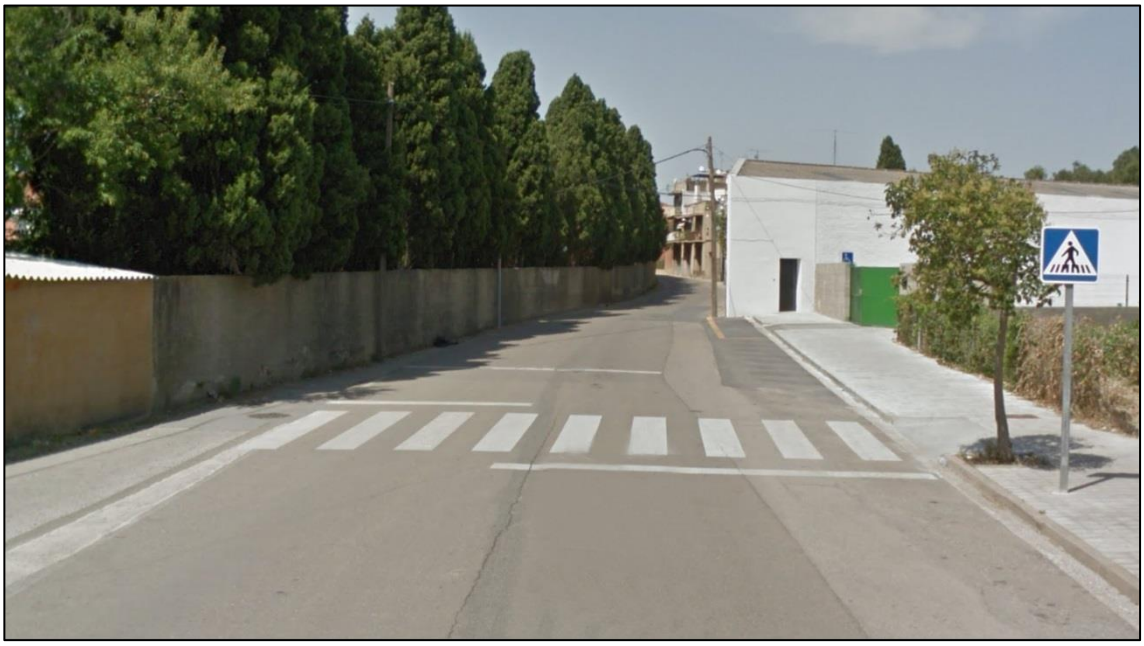

Figure LXX: The bottleneck of Passeig de Vilatenim just before the level crossing. Note how the street is otherwise very wide.

The southern stretch starts with the intersection between the new road along the railway corridor and the east-west *Avinguda Vilallonga*. It is not clear how this intersection should optimally be designed. A roundabout would surely help achieve a smooth traffic flow, yet it would create a barrier for pedestrians, precisely what the railway now represents. On top of that, there is not much space to accommodate a roundabout. A junction seems to be thus the most suitable option. Just south of the previous location, there is currently a hundred-metre long street that gives access to the railway and bus station. Across the railway, there is a very narrow dead-end street. The new road would run directly above the railway, as it would further north; and the previous two streets would become pedestrian areas. The road would run past the current station building, which could very well continue to serve its purpose in the new situation with underground platforms after being remodelled on the inside. Further south, the space along the railway consists of empty plots of land that is used for little more than parking cars. The new layout would see six existing streets connect to the new north-south road, of which four are currently come to a dead end.

Two of these streets would be arranged such that they create a four-road junction. The aim is to exploit the currently dead-end roads east of the railway as entrance/exit points to the city. The entrance to these roads (currently a dead end) is shown in Figure LXXI, and while it is not wide enough to be used as main road, it may very well be able to convey quite some traffic.

Figure LXXI: The currently dead-end road located east of the railway. This road intersects the ring road and is largely underused because of this dead end, despite having considerable width. This would surely change if it was connected to the street network across the railway, something that should be done if the latter was put underground.

Further south, a one-way street currently runs again along the railway for the last 370m of north of the underpass. As previously mentioned, the first option, in Figure LXXII; considers the last 350m of railway to remain above ground. The new road would head south-west and meet one of the current dead-end streets at the very location shown in Figure LXXIII. The road would then head south, along the existing street; however, widened to the necessary width to convey two-way traffic. Although along this stretch, the railway would not run underground, the reduction in the number of tracks brought about by the whole intervention just north of it would relieve space to make this widening possible. The last 150m north of the underpass are too narrow to accommodate a second lane, as shown in Figure LXXIV; which means vehicles heading south would have to be conveyed through another street. The southernmost 150m long stretch of the new road would therefore only convey northbound traffic. Exit and entrance to the road from the ring road would not be direct, involving a couple of turns.

Figure LXXII: The envisaged layout of the southern stretch according to the first option. Note the location of the central bus station.

Figure LXXIII: The railway would be put underground up to the location shown in the image. This is also the point where the new road would shift onto an existing one. Note the gap between road and railway. This means the road can be widened to accommodate a second lane. Note also how, despite the abundant space, the barrier posed by the railway results in this space being used as no more than car park.

Figure LXXIV: Close to the underpass, the gap between railway and road gets very narrow and a two-way street could no longer fit.

The second option considers putting the railway underground until just after the underpass. This means there would be no space constraint for the new road, which would run directly above the railway until the current underpass. The latter, shown in Figure LXXVI, would disappear; as the road would be raised to match the level of the surroundings. A roundabout would join the ring road, new road above the railway and existing one-way street south of this point. Access to the new road would be quick and direct, unlike in the previous option.

Besides the southernmost stretch, the new layout would be almost equal in both options. Some blocks would be built up, according to the current street layout; most of which are already partly built up. In such cases, some secondary streets may be added to provide access to garages. Most of the relieved space; however, would consist of green areas, thereby making the new road an avenue. The latter, however should not have more than two lanes (one for each direction), to ensure the barrier effect of the railway is not worsened by this avenue. There should be enough pedestrian crossings and preferably also a bike lane. The aim of the whole project is to improve mobility and reduce congestion in the city, yet a road with very high capacity might increase car use among residents, something which is highly undesirable in a city with very narrow streets and the potential to shift towards other transport modes such as cycling (*Figueres* is largely flat).

Figure LXXV: The envisaged layout of the southern stretch according to the second option. Note how the built-up space would roughly be the same.

Another element to consider is interurban buses. The central bus station is located one block from the railway station, as shown in Figure LXXV, arguably not the optimal location; yet it offers a quick transfer between bus and train. The bus station lies in a high building density area and there is only one access point. Access streets are narrow and very busy. Currently, buses have to exit through *Avinguda Vilallonga*, thereby further contributing to congestion. The new avenue and other changes to the street layout brought about by putting the railway underground could have an important impact on this. Most interurban buses head west, to the cities of *Banyoles* and *Olot*; only buses bound for *Roses* and *Cadaques* head east. Currently, most buses wind their way through narrow streets across the city. This gives rise to congestion, noise, etc.; as well as limiting the size of buses. An option is to relocate the central bus station to a more accessible nearby location. A block further east, next to the railway station, would be a suitable location. Conversely, the bus station could be left as it is, yet buses would enter from and exit to the new avenue. Instead of driving across the city centre, buses would use the new avenue and other wide streets to bypass the narrow and busy streets. This would obviously only apply to interurban buses, which also stop at *Plaça del Sol*, in the west part of the city. In the envisaged scenario, buses would continue to stop there; and while they would make some detour as compared to the current situation, the benefits to the city centre would be worth it. Additionally, buses may also stop somewhere in the south. This new situation would only really be applicable if the second option is chosen (railway runs underground until the ring road), as otherwise, the detour would be too long to justify it.

Figure LXXVI: The underpass of the ring road. The second option contemplates raising the road to the level of the surroundings and building a roundabout right above the railway.

The four options can be combined into four possible cases. The optimal case will be the one whose layout provides the most benefits as compared to the estimated cost. Let us analyse in the first place the vehicle flows within, into and out of the city.

There are five main entrance/exit points in the city of *Figueres*. Two of them (north and west) have little to no relation with the area along the railway; as the overwhelming majority of vehicles leaving or entering the city through those points do not get anywhere near the railway corridor. The other three entrance/exit points convey vehicles that do travel across or along the railway. To figure out the potential number of vehicles that may use the new road along the railway corridor and surrounding streets, let us split the city into several regions. Concretely, for every entrance/exit point, we may discern three different regions from which vehicles originate and for which they head. Within a street layout such as that of Figueres, a few main streets convey the bulk of the vehicles; this makes it possible to discretize the area of the city. Next, let us analyse average daily traffic figures for the main entrance/exit roads. First, in the east, a coverage station on road C-260 measured an ADT of 22287 vehicles/ day in 2016. This station is located some nine kilometres east of the city, and there is a major interchange in between. Let us suppose that, past the interchange of road N-II, vehicle flows on and off the road cancel out and the ADT on the stretch of road C-260 that is closes to the city stays the same. The percentage of vehicles travelling in every direction is approximately equal, at 49%-51%. We may consider ADT figures to be split equally between both directions *(ref.8)*. Second, in the northeast; road N-260 saw an ADT of 11210 vehicles/ day in 2016 *(ref.9)*. Third, in the south, road N-IIa, the busiest entrance/exit point saw roughly 25000 vehicles/ day. Last, road GIV-6211, in the southeast is a minor road that only serves one small village. There are no traffic records, yet we may assume an ADT of no more than 500 vehicles/day. We may therefore disregard the latter road for the analysis.

Figure LXXVII shows the traffic flows in and out of every region. Note that these flows do not completely correspond to the current layout, but are estimated for the scenario in which the railway was buried from overpass in the north to underpass in the south (longest stretch possible). We assume all traffic volumes to be equal in both directions; hence, for the sake of simplicity, let us exclusively talk about vehicles entering the city.

Vehicles coming from road C-260 spread out at the first roundabout, on the ring road. Only vehicles heading for the very north, south and west of the city take the ring road to bypass the city centre. Most vehicles (some 60%, many of which non-residents) head straight for the city centre. Within this region, we may discern two sub-regions and corresponding traffic flows; namely, those vehicles heading for the inner city and those heading elsewhere. Within the former sub-region, not many vehicles would use the new road along the railway, within the latter; however, close to all vehicles would, as they would save a lot of time as compared to the current route through the inner city. The road shown in Figure LXXI, some 200m south of C-260, may convey some of these vehicles.

Vehicles coming from road N-260 also spread out at the first roundabout. Vehicles heading for the south of the city would take the existing ring road, even in the scenario where a road runs above the railway uninterruptedly. Drivers would likely opt for the existing ring road, because of its higher capacity, shorter travel time and the fact that the ride would be only about 100m shorter if they did otherwise. The bulk of the traffic of road N-260 would continue straight into the city on the same road. Only a small fraction, roughly 15% of vehicles, would turn onto the new road along the railway.

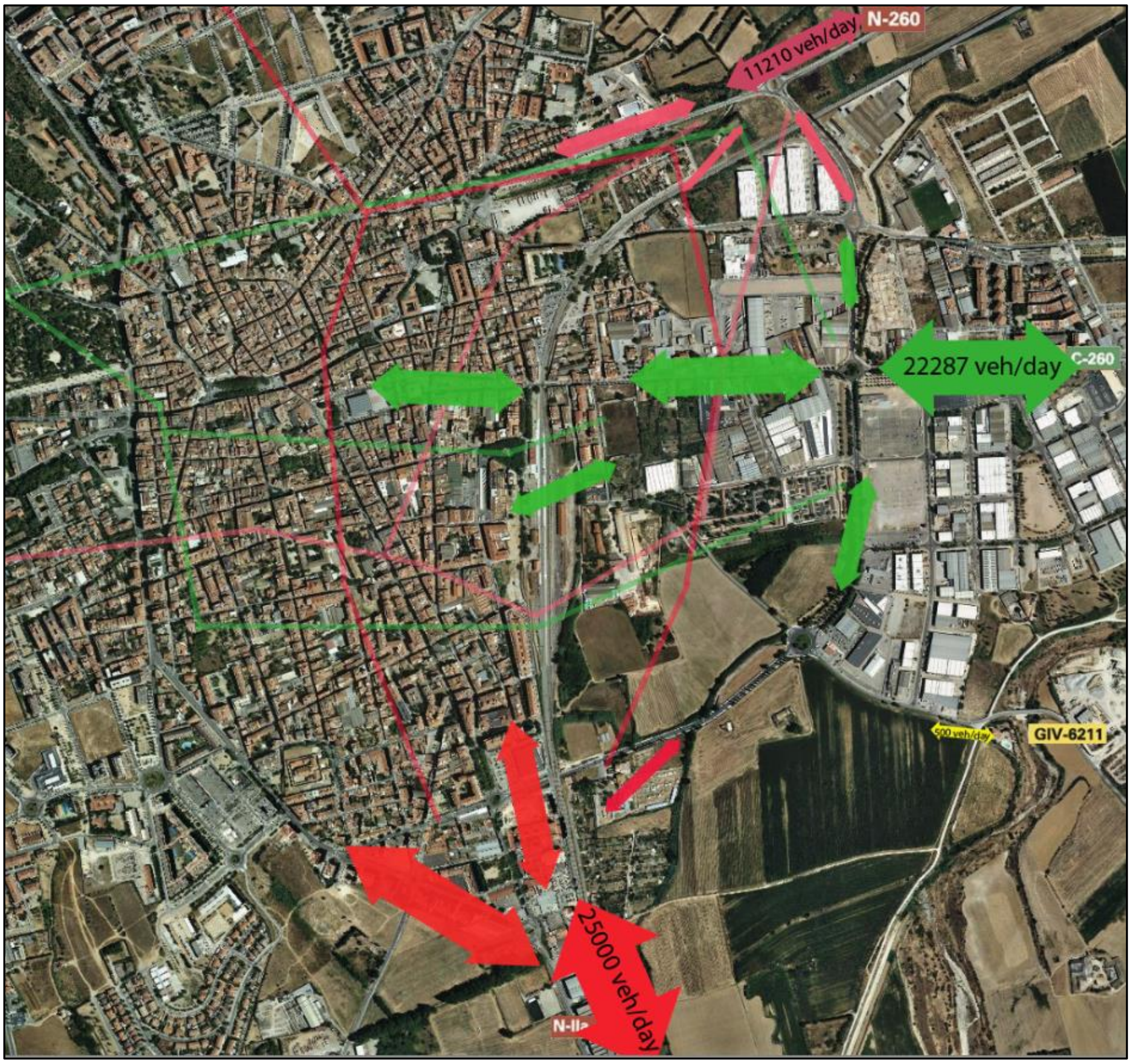

Figure LXXVII: Traffic flows in and out of the city. Green arrows denote traffic flows on road C-260; red arrows, on road N-IIa; and pink arrows, on road N-260.

Vehicles coming from road N-IIa, by far the busiest of the three entrance roads, would also spread out very unevenly; whereby the bulk of the vehicles would continue on road N-IIa, which runs as an avenue across the city, and from there they would be conveyed to their destination. A tiny part of the vehicles, those heading for the very north, would take the ring road to bypass the city. The remaining part, making up roughly 35% of the vehicles entering or leaving the city through road N-IIa in the south; would travel along the railway corridor or nearby streets running parallel to the latter. If the new road along the railway was readily accessible from a roundabout, that is if the railway is buried along the entire southern stretch; it could convey a large chunk of that 35% of vehicles.

The analysis of the traffic flows indicates that the enhancement of the street layout brought about by the whole intervention would prove beneficial to reduce traffic density within the city as some traffic of every entrance point would divert onto the new road. The amount of vehicles conveyed along southern and northern stretch is however very different. The former would convey a considerable share of vehicles entering/exiting through roads C-260 and N-IIa, which are also the busiest roads. The northernmost stretch of the new road would only see a small number of vehicles. The conclusion that can be drawn from all these factors is that, in the northern stretch, the railway should not be put underground up to the ring road because of the small traffic volumes that would much likely be conveyed. These vehicles might as well just enter/exit the city through road C-260 (*Avinguda Vilanova*) or *Passeig Vilatenim*. Conversely, the southernmost stretch of the new road seems to have the potential to attract large traffic volumes. If the latter does not run up to the ring road, thereby the access to the latter not being as direct, vehicles may very well opt for another parallel street, which would reduce the full potential of the new road. Therefore, it seems that putting the railway underground up to the current underpass is a good idea. The difference in cost as compared to the other option will tip the scale in favour of one of them to decide which option is definitively better.

To sum up, the benefits of putting the railway underground in the city of *Figueres* would be the following:

- Disappearance of the barrier effect in the north of the city, thereby bringing communities closer together.
- Improvement in visual quality and noise levels for some 1200 households, the latter seeing rather little improvement as road noise is no better than rail noise; which would likely drive up property value.
- Revival of the currently largely decayed neighbourhood east of the railway and land adjacent to the railway in general, which would definitely become more functional.
- Removal of level crossings, whose barriers currently close exaggeratedly early; and subsequent time gains.
- Enhancement of the currently limited street layout, thereby reducing congestion, noise, pollution, travel times and having some positive impact on the economy of the city.

These benefits are very difficult to monetize, both because of their intangible nature and because they arise from an envisaged scenario, which is uncertain; which means some of the benefits might not turn out as expected. All in all, the situation of the railway in *Figueres* seems to fulfil the criteria to make a modification justifiable. The likely benefits to be obtained back the project. From the financial side, there do not seem to be any major technical difficulties, unlike in *Girona*, for example; that would drive the cost unreasonably high. The project looks thus, a priori, both feasible and justifiable. This does not mean it is a priority, yet it is a reasonable project and not a whim.

Let us now move on to the costs. To estimate them, we need some technical data of the stretch of railway to be modified. The project would entail putting the railway in a trench and subsequently covering it along the desired stretch. The rest of the trench would remain uncovered and its depth would range from that of the covered stretch to ground level.

Tunnel cross sectional dimensions result from clearance requirements of the railway. The rolling stock running on this railroad consists of passenger trains intercity S-449 and commuter trains S-447; and freight trains, usually powered by locomotives S-253. The cross sectional dimensions of these machines are stated on the website of the Spanish national railway operator: freight wagons are narrower than locomotives; so are car carriers, which are not uncommon on this railroad. The governing dimensions are a height of 4300mm (S-449) and a width of 2997mm (S-253). The required width results from a track axis to axis separation of 3,80m and a 1m clearance between walls and governing rolling stock width. *(ref.10)* The required width is therefore 8,79m.

Tracks are ballastless along tunnels; which means sleepers rest directly on the floor concrete slab. The required height results from a height of the sleepers of 250mm, a height of the UIC-45 rail of 159mm, a height of 5,30m from running surface to contact wire and a height of 1,40m from the latter to the top of the catenary. The required height is therefore 7,11m.

Since we are dealing with a conventional railroad within a slow-speed stretch, the minimum clearance requirements suffice and additional clearance imposed by pressure conditions at high speeds do not apply here.

The cross sectional dimensions of the tunnel are shown in Figure LXXVIII. To obtain the total dimensions of the trench, we have to add to the tunnel cross section the thickness of the cut and cover box. Floor slab, side walls and ceiling slab may all have a different thickness. For now, only the latter is needed in order to know the depth of the railroad. We may use a ceiling slab thickness of 50cm, which is commonly employed.

Let us now move on to the vertical alignment. The previously calculated depth, along with the slope constraints and the shape of the terrain above it will govern the length of the stretch of railway to be modified.

Figueres is a largely flat city. When compared to many other previously discussed cities, such as *Vilafranca del Penedes*, the land adjacent to the railway does not present large irregularities that force to bury and cover the railway along certain stretches and leave it above ground along others; and if the latter are buried, the length of the stretch to be modified is often so long that it is not even considered. We are, thus dealing with a favourable topography.

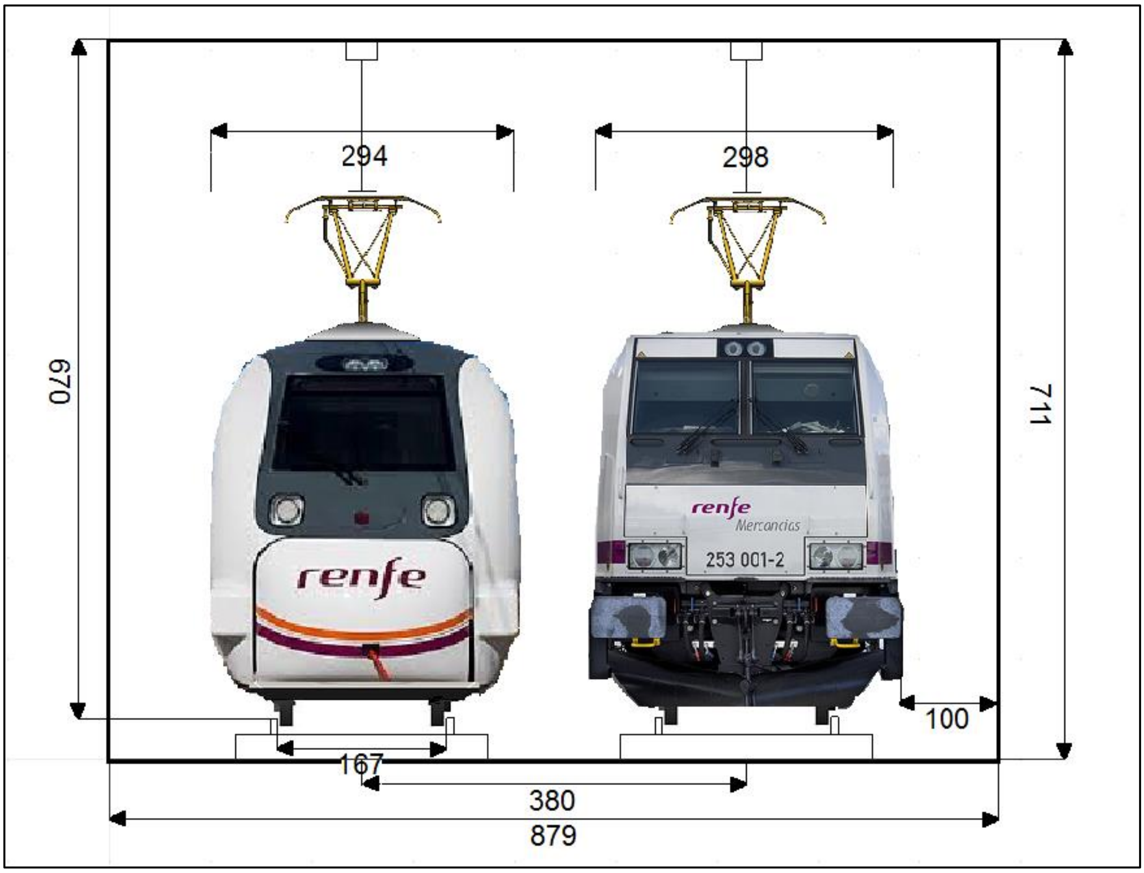

Figure LXXVIII: Cross-section of the tunnel. Note the position of the contact wire just above the pantograph.

However, the ground and in turn the railroad running at grade, does not lie at a constant height across the city. The city sits on a small hill, whose foot reaches the railway. A topographic profile of the railway confirms it. The latter can be easily constructed with a few control points. From north to south: under the overpass (A), the railway runs at 20,5m above sea level; at the northern entrance of the envisaged underground stretch (B), at 24,2m; at the first level crossing, at 25,5m; at the second level crossing (C), at 27,6m; at the southern entrance of the underground (E) of the first option, at 27,5m; at the underpass, at 27,36m and some 360m south of the underpass, at 26,4m. These numbers correspond to the level of the railway, yet as drawn from several pictures, the level of the adjacent land is the same. If the profile is drawn, different slopes can be observed and, if very similar, simplified and merged. The outcome is a slope of 1% from the overpass to the northern end of the underground stretch, a slope of 0,64% from the latter to the second level crossing, a flat stretch from the latter to the underpass, and a slope of -0,26% further south. The central stretch, which hosts the station, runs at a constant level and slightly elevated with respect to the rest of the railway.

A transition slope has to join the new underground stretch and the existing above ground railway. The maximum permissible slope for freight trains will be used for this purpose: 1,5%. A sudden change in slope has to be softened by a transition curve. The radius of a transition curve can be calculated as: $R = \frac{V^2}{4}$, where V is the maximum speed that trains reach around the curve. We do not know the maximum speed at any location, as there are no signals along the entire stretch that runs through the city. The maximum speed admitted on the curve between points B and C can give us an idea of how fast trains travel when approaching and leaving the station. This speed can be calculated as: $V = 4{,}5 * \sqrt{R}$, where R is the radius of the curve *(ref.10)*, in this case 460m. This gives a speed of 96,5km/h. This could be assumed as the maximum speed along the stretch of railway within the city. Although freight trains do not stop at the station, their speed is rarely higher elsewhere. The radius of the vertical transition curves can therefore be assumed at 2330m. The larger the gradient difference of the slopes to be joined, the longer the transition curve will be.

Moving from north to south, see Figure LXXIX, if the railway is to run underground from point B, a trench with a slope of 1,5% plus transition curves has to be dug up to the point where it meets the current railway. This point happens to be the overpass, and the length of the open trench is relatively small because of the sloping terrain above. At the tunnel entrance, the ceiling slab runs at ground level. Two options can be considered, namely, that the railway runs at a constant level along the underground stretch or that it slopes back upwards with a slope smaller than the ground level, namely <0,6%, to match the terrain. The first option means that at location C and further south, where the terrain evens out, the ceiling slab would be located 3,4m deep. In the second option, this depth would only be a metre, yet because the slope difference at point B is larger, so is the transition curve and total length of the trench. If the slab was not built at ground level, in order to make the trench shallower, the tunnel would stick out of the adjacent land. This is not desirable, as the adjacent streets and level crossings cannot be modified. South of point C, where there is more room for modifications, the ground level could be lowered some half a metre to a metre in some sections to make the tunnel shallower.

The stretch from the level crossing C to E, consisting of the station, would be flat, as it currently is. Point E also happens to be the end of the underground stretch of the first option. The underpass of the ring road, 15m wide and 6,5m high at location F is located 380m south of point E. The question that soon pops up is whether the railway would make it to the surface before the underpass in the new layout. The first option (Figure LXXX, top) would see a slope of 1,5% with transition curves bring the railway from point E back to the surface.

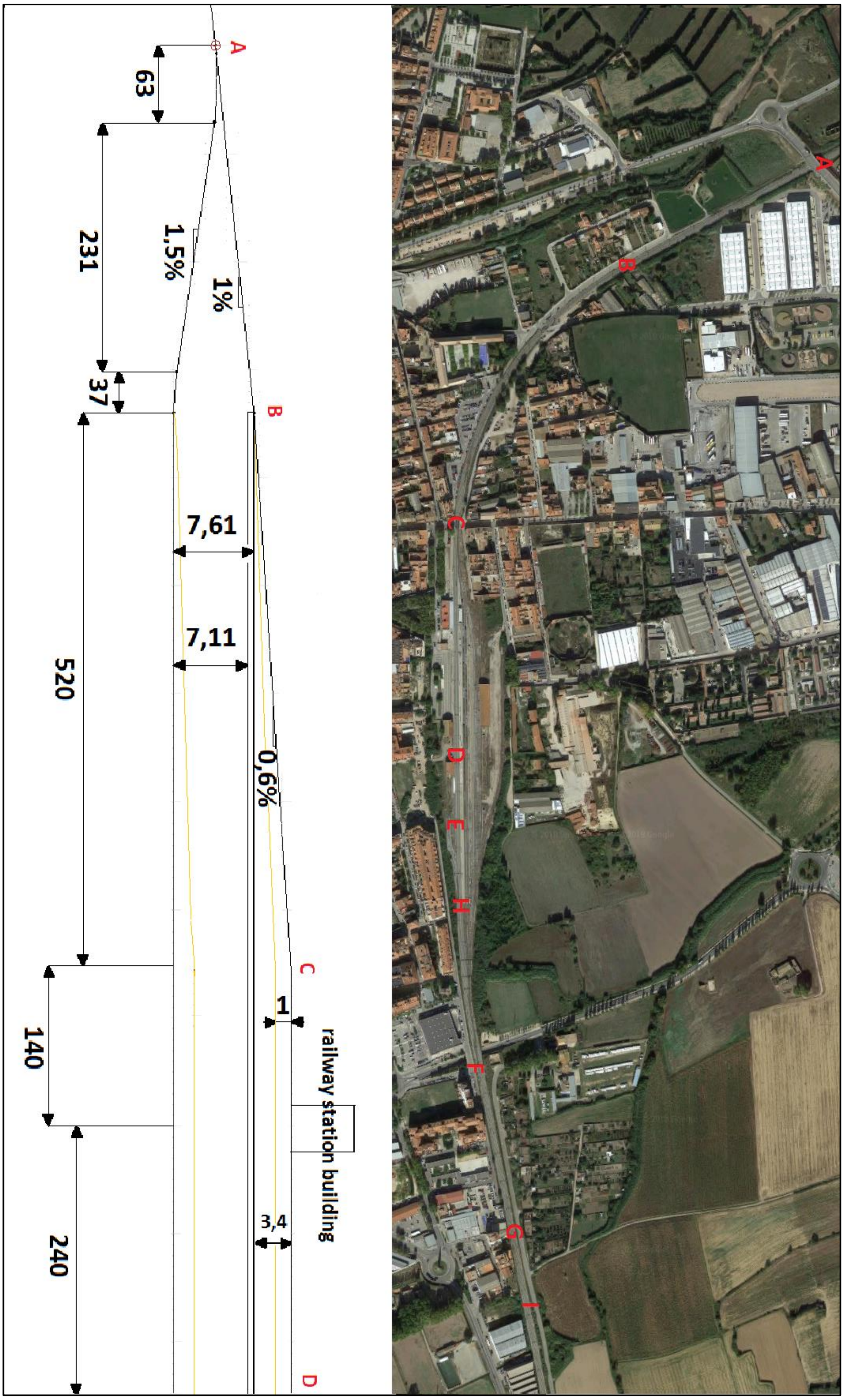

Figure LXXIX: Side view of the stretch AD. From B to E: in black, the profile if the railway runs at a constant level; in yellow, if it does so only from C to E. Measures are in metres.

Regardless of whether the railway runs deep or two metres shallower, it would cut through the underpass. For the railway to make it to the surface just before the underpass, the tunnel entrance would need to be located just 90m south of the station building, reducing the total underground stretch to a mere 750m, meaning the open trench would be longer than the covered one. This would also mean the tracks would run on a slope within the station, which is not desirable. The underpass would therefore have to be modified. Deepening the underpass up to five metres is possible yet not very attractive, as an overpass might as well be built.

The second option (Figure LXXX, bottom) would see the transition slope take off long before the tunnel entrance. The location to do so to must ensure that at the tunnel entrance, the ceiling slab lies just beneath the surface. If the railway runs at a constant level along stretch BC, then such location is H. If it does not, it is 160m further south. Yet, the length of the trench remains the same regardless of the depth of the underground stretch, namely up to point I.

The first option would see the railway come to the surface at point G, 125m north of point I in the shallow option and 245m north of point I in the deeper option. The total stretch to be modified is therefore not very different for the first and second options, despite the latter seeing a 412m longer underground stretch than the former. Both options would see the underpass having to be rebuilt. In the first option, the road would have to be lowered some four metres and a new railway bridge would have to be built. In the second option, on the other hand, the underpass would be sealed to build a new road above, at ground level. The latter seems, at first glance, more economical.

Before dealing with the costs themselves, it is clear that putting the railway underground up to the underpass would be more expensive than otherwise. Yet the benefit-cost ratio seems to tip the scale in its favour. The other option would see an all too long stretch run in a trench, which is more costly than the deck that covers it, which means that the investment would still be large yet the benefits would be rather limited and the city would certainly not make the most out of the project. The second option therefore seems to be more appropriate.

Another yet more economical option, proposed by the municipality in the light of the shortage of funds to make possible the construction of a long underground stretch; is to put underground a short 200m stretch comprising the level crossing on *Avinguda Vilallonga* and some part of the station. This would not solve much of the integration problem of the railway in the city as it would only result in the suppression of the level crossing, which is not the only culprit of the problem. It may still be justifiable to cover such a short stretch, yet the very long stretch to be modified (in trench) points to a very small benefit to cost relation and means the city would lose out on experiencing the full consequences of a fully covered railway.

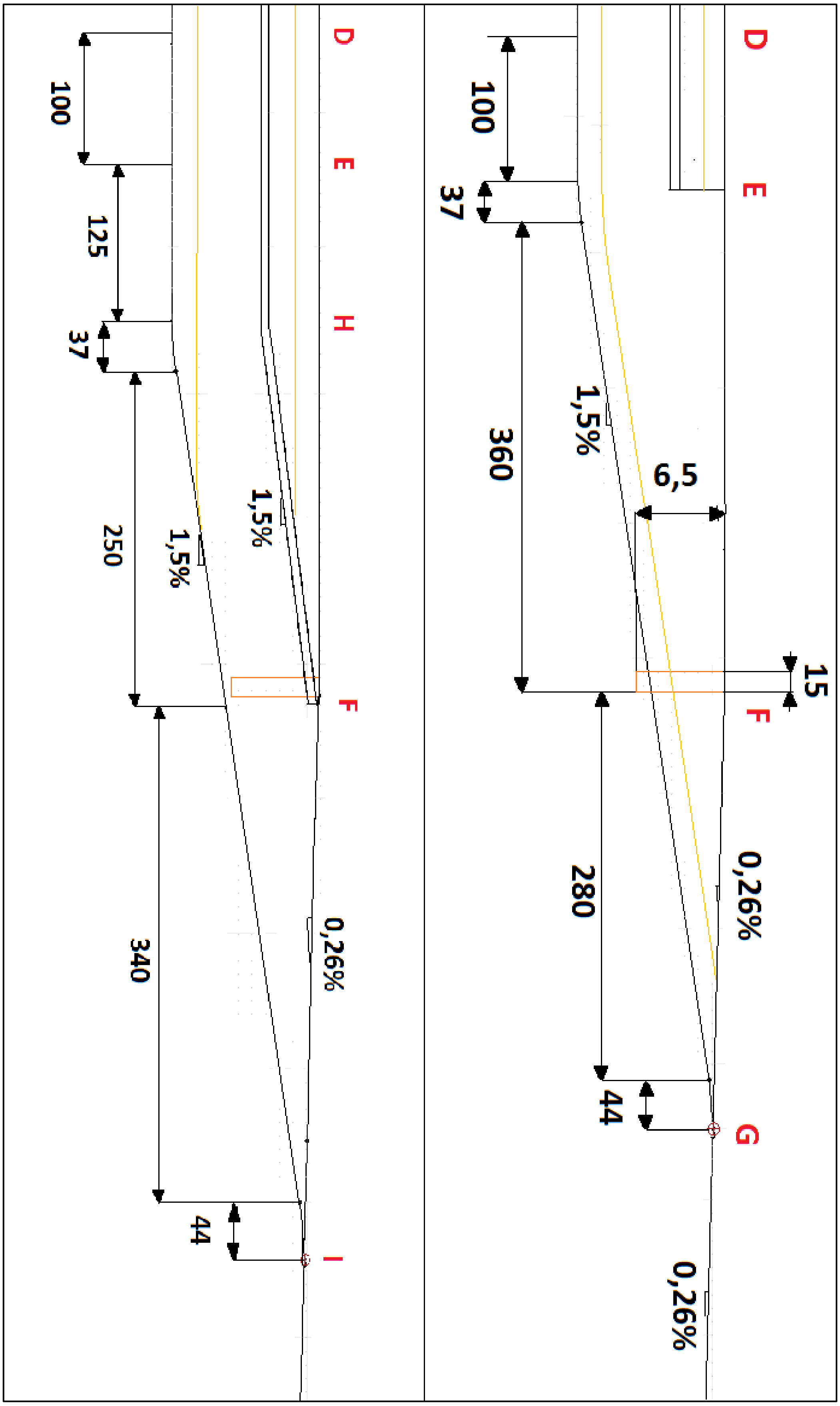

Figure LXXX: South of point E, the profile is different for the first (top) and second (bottom) option. The vertical dimension is enlarged 10 times.

As far as the depth of the ceiling of the underground stretch that should be chosen, it seems that 3m is excessive, and it is uncertain whether the overlying land can be dug out to reduce this depth. If the railway is put underground until the underpass, the total stretch running in a trench would be some 37m longer for the shallower option. Yet, digging a deeper trench along over a kilometre is more expensive, and the ceiling slab would have to bear more weight. These factors indicate that the ceiling slab should not be more than a metre below ground level. Since the city sits on an alluvial deposit with a thickness of some 6m consisting of gravel and sand, is it not likely that the excavation will reach the bedrock, which will avoid cost overruns.

When it comes to the course of the railway, that is the top view; it would be the same as the current one along the stretch north of point C and south of point F. Along the central stretch; however, there is room to consider several options, all of which have to fulfil a number of conditions and have their pluses and minuses.

One of these conditions is the number of tracks that the new underground station would have. Currently, the station has five tracks and two platforms. Reducing the number of tracks does not necessarily have to prove a constraint for the railway service. Cutting down on the number of tracks to just two would substantially drive costs down as it would mean the trench would not be much wider along the station than along the rest of the tunnel. Yet two tracks would surely prove insufficient for the current passenger and freight train traffic, expected to remain steady. Terminus services, which make up half of the total traffic, would be severely constrained. At least three tracks would be necessary to accommodate the current traffic, whereby one of them would be used for terminus services as well as stationing passenger trains at night to keep at least one track clear for freight traffic. Three tracks would be enough to bear the current frequency of lines R11 and RG1 and freight trains. The station would therefore have two platforms. The second condition is that there is direct access to the platforms from the station building.

The first option consists of digging the trench roughly below the current station building, as shown in Figure LXXXI, thereby shifting the main tracks westwards just enough so that the platforms lie just beneath the station building, which would be preserved yet would have to be widened. The new street layout would no longer be as depicted in Figure LXXV, as the main road would run some metres further east.

The second option consists of digging a trench along the central stretch that comprises the current two main tracks and the first side track (on the east). For this, the new road would have to be split into two lanes, one for each traffic direction, with a wide promenade in between. A new station building would have to be built in the middle. See Figure LXXXII.

Figure LXXXI: The street and railway layout if the trench was dug west of the current tracks. Note the tunnel in yellow, the tracks in black and the overlying street layout in grey. Note how the station building would need to be widened just enough to overlie the platforms.

Figure LXXXII: The street and railway layout if the trench was dug along the current tracks. Out of the three tracks, the two that are farther apart would have a platform in between.

The two options are very similar and have their pros and cons. The first one would involve the construction of a smaller road length and area, yet this difference would be small. The current station building would be preserved. The second option, on the other hand, would have a smaller barrier effect (along a very short stretch) as a two-way street has a more negative impact on the pedestrian network than two one-way streets. In order to make the most of the new street layout, all streets running perpendicular to the new avenue would convey and feed the latter with both southbound and northbound traffic. To accomplish this, the first option would need traffic lights in at least three of the five intersections, as well as the one with the busy *Avinguda Vilallonga*, where a roundabout is an option. The second option, on the other hand, would not need any traffic lights, thereby cutting down on travel time.

If the railway corridor ran through a built-up area, the second option would likely be chosen over the first one. This is not the case here. Though both options are perfectly valid, let us stick with the first one, as it would clearly be more economical and both options seem to be able to deliver similar results as far as traffic flow goes.

Figure LXXXIII shows the cross section of the station. The current building would have to be widened five metres, so that escalators and a lift can fit in to provide access to the platform below. The platforms would have a similar width as they currently do.

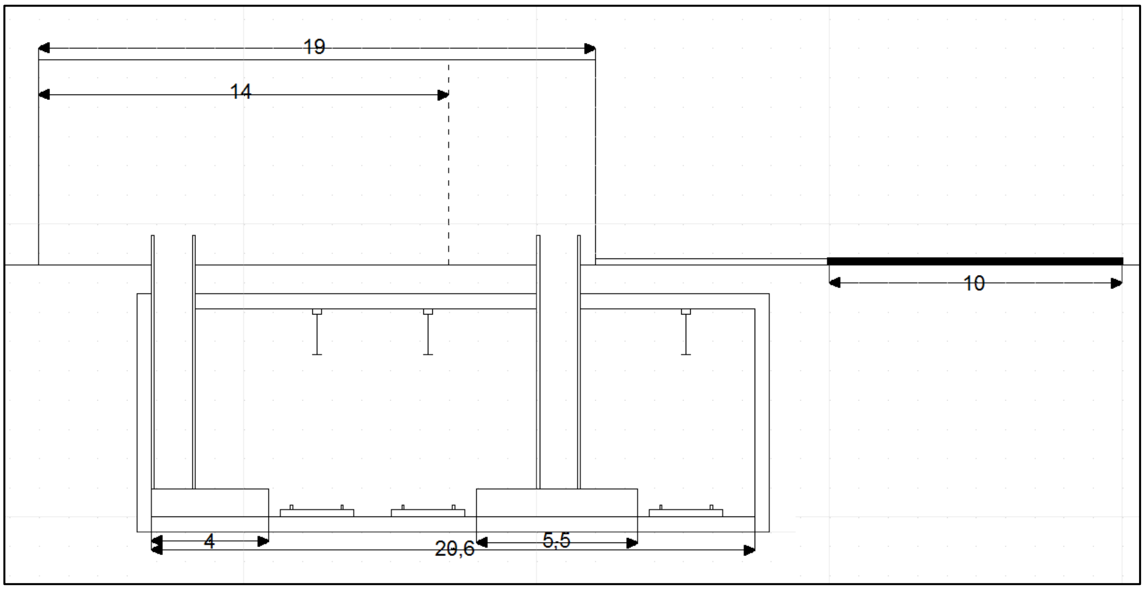

Figure LXXXIII: Detailing of the station cross section. Note the current station building (dashed line) which is just too short to fit in escalators and a lift to the platform below. Note also, on the right, the new road. Optimally, the station should be accessible from both sides.

The chosen option would see a stretch of 1,30 km run underground and covered, of which some 510m have three tracks and the rest, two tracks; and a 715m stretch run in a trench. A very simple estimation of the costs can be made by using illustrative figures for the costs, as discussed in section 4.4. If we take 21M€/km as the indicative cost for a two-track cut and cover tunnel and 25M€/km for three tracks plus platforms, 10M€/km for a trenched stretch and some 2M€ for the station adaptation, the total cost seems to be somewhere around 38M€. The urbanization of the relieved space and reconstruction of the road of the former underpass are not included.

7. Conclusions

This thesis started out with the dilemma of how urban areas should deal with the negative impacts of railways. After analysing these impacts and the numerous measures to tackle them, and making a thorough reflection on the right way to approach the problem; we can draw a set of conclusions.

The barrier effect is a very real issue that is more often than not disregarded. Despite not being attributed a substantial economic value, the barrier effect can result in urban spaces being literally lost and deteriorated up to the point of losing all their functionality and liveability. Investments made to alleviate the barrier effect, while having no financial return, rarely turn out to be a waste of money if they are really necessary and the use of the relieved space is well thought of. Railways do pose barrier effect, yet so do highways and even streets with a high speed limit. The negative impact of roads and highways within urban areas is often disregarded despite being very often worse than the railway's. They are commonly measured with different yardsticks and the railway is usually unfairly blamed for poorly functional city layouts. This practise should come to an end; railroads do have some negative impacts, yet so do all kinds of linear infrastructure.

The author maintains a firm stance on what the primary goal of urban planning authorities should be; namely, alleviating the barrier effect and other impacts by means of measures that do not modify the railway but the surroundings. In Catalonia, in particular, it is important that authorities change their attitude towards the integration of the railway. According to this, every analysis in a particular city where negative impacts of the railway are proven to be large enough to take action should start by listing out possible alleviation measures. There are many of these measures, which are nowhere as expensive and can be just as effective as the heavy duty approach, namely modifying the railway. However, their applicability is conditioned to a certain physical context. These measures range from building wide and pedestrian-friendly under and overpasses to refurbishing and rethinking the use of land adjacent to the railway. In many cases, a great part of the problem may be down to the poor aesthetics of the border railway-street along with the negligence of some railway facilities such as the presence of unused tracks, abandoned yards, run-down fences, etc. It is therefore necessary that, in every particular case, the rail authority collaborates with the municipality to ensure a proper integration of the railway within the surroundings.

There should be no need to implement measures to integrate the railway in the first place. If the latter is integrated within the surroundings from the very beginning by making use of clever urban planning, there is nearly full certainty that there will not be any need to modify the railway in the future. There are again several strategies to accomplish this. Building railways in trenches or on embankments, leaving a wide gap between buildings and railway, making use of trees and hedges instead of plain metal fences, concentrating industry along the railway are all strategies that may come too late to most existing urban areas with railway-related issues; yet should always be applied whenever possible, especially in future developments.

Integrating the railway is; however, not always possible. There are cases where the barrier effect is so severe and there is so little room for mitigation measures that it is inevitable to resort to modifying the railway. The list of criteria to justify doing so is as introduced in section 4.6; among them being a high population density and a poor street layout. They are only indicative, but are certainly of good use to, at first glance, identify justifiable interventions and undermine those that are rather a whim. If the railway is to be modified, the best option is always to put it underground, in order to kill two birds with one stone and get rid of other issues like noise and visual impact. Nevertheless, if a viaduct fits better within the particular physical context and the cost difference is substantial; it could be perfectly implemented.

There are certain street layouts that are not compatible with above-ground railways. Narrow streets enclosing small blocks with attached buildings create a very dense space in which railways do not fit and take up a very valuable space. As a result, crossing points are difficult to fit in and are usually not very functional. On the other hand, street layouts with wide streets and big blocks with detached buildings, which might result in a city having a higher population density than one with the former type of layout; can coexist with above-ground railways, as the street layout can usually just be extended across the railway, thereby causing the latter little to no disruption. Urban areas with these features do not experience much nuisance from the railway other than noise, which is comparable to a road's.

Catalonia has, along with Spain, by far the highest percentage of railway running underground through urban areas out of all countries in Europe. This percentage, which is still tiny, can be attributed to the high population density of Catalan cities and the incompatibility of their street layout with the railway. Furthermore, railways running at street level are very common in cities in Catalonia, something that is hardly ever observed in other countries, where most railways run either in trenches or on embankments, which means under and overpasses are easier to fit in, thereby alleviating the barrier effect. These factors indicate that railway integration approaches commonly used in many countries do not generally apply to Catalan cities. Claims to put the railway underground should therefore not be rejected on the basis that above-ground railways and urban areas successfully coexist in many places across Europe.

Railways can perfectly run above ground if the physical context allows it; yet there are several cities in Europe (outside of Spain) that meet the criteria to have the railway put underground, and it is recommended that they do so; yet, the authorities' willingness to fund the interventions is often missing.

All interventions to put the railway underground in Catalonia have proven a success. Despite some of them arguably being not necessary, the outcome has always been very positive for cities and cannot be deemed a waste of money. For these reasons, projects to modify the railway should not be immediately ruled out even if they appear far-fetched at first. Citizens of Catalonia should be proud of the willingness of the authorities to modify the railway as compared to other countries.

There are a few municipalities in Catalonia that meet the criteria for the railway to be put underground. They are: *Montcada i Reixac*, *l'Hospitalet* and *Sant Feliu de Llobregat*. The commitment to the intervention in the first two cities, recently announced by the authorities, was without a doubt a very wise decision, as in all three particular cases something needs to be done yet there is no room for alternatives. Other approved projects, such as *Sabadell* and *Granollers*, where the railway does not pose a severe problem, should be rethought; and the two municipalities should bet on alleviation measures instead.

As far as the other five major cities in which the presence and integration of the railway has been thoroughly analysed; we can conclude that only in one of them, namely *Figueres*, it is recommended to put the railway underground. Although, at first glance, it may seem that the railway does not pose much nuisance in this city to justify such a radical intervention, especially when looking on an aerial image, experiencing the problem first hand tells; however, a different story. The barrier effect is nowhere near as severe as in cities like *Montcada i Reixac*, as the size of the area and the number of people affected is rather small. The railway in *Reus*, for instance, actually poses much more barrier effect than in *Figueres*. Despite all these facts, *Figueres* is still, hands down, according to the analysis performed in this thesis, the only candidate to have the railway put underground out of the five cities. This is due to a number of reasons:

First of all, *Figueres* appears to have by far the worst integration of the railway. This can be seen in the surroundings, which have decayed more and more over the years and are used for nothing more than irregular car parking. *Girona* may have a viaduct running through a very densely built-up area and signs of decay along it are obvious; yet, the space under the viaduct seems to start to be rethought, being used as a bike lane, among others; something which is not applicable to the city of *Figueres*. The poor integration of the railway in this city, unlike in *Tarragona* and *Reus* is not down to the negligence of rail facilities, but to the presence of the railway itself. This means that in *Figueres* measures have to be taken on the railway and not on the adjacent land.

Even though the few communities that are cut off from the city by the railway only have 2150 inhabitants; there is a very large percentage of people belonging to disadvantaged social groups such as the elderly, immigrants and people living on a low income. The presence of a barrier like the railway unfortunately further worsens segregation.

Noise nuisance is much more present in cities like *Girona* and *Tarragona*, which see much higher train frequencies than *Figueres*. Yet none of the five cities experience rail noise nuisance that is severe enough to be much worse than road noise, except for a 250m long stretch in the city of *Girona*, which is the main reason to consider putting the railway underground altogether.

The decisive factor is the particular layout of the city of *Figueres*. The city consists of very narrow one-way streets that rely on one single entrance/exit road to the east. There is a need for a two-way street to convey north and southbound traffic in the east of the city. It is firmly believed that this street will relieve the congestion that is typically found in the city centre. The city of *Girona* could improve its street layout by turning the space that is currently occupied by the railway into a wide continuous street and so could Tarragona. Yet these two cities do not seem to be in great need of enhancing their street network, as no congestion or severe lack of accessibility was observed during their analysis. The benefits of burying the railway in *Figueres* would by far be the most significant. Putting the railway underground in *Tarragona* would definitely boost tourism and property prices in the city, as it would give the waterfront a complete makeover, thereby making it much more attractive than it is now. The project would thus likely turn out to have significant economic benefits in the city, much more than it would in *Figueres*. However, as previously stated, putting the railway underground in *Tarragona* is rather based on aesthetic reasons, which does not mean it is not an appropriate project; yet it should certainly not be funded with taxpayers' money. On top of that, there is room for alternatives.

The benefit-cost ratio in the case of *Figueres* is favourable. Although it is not possible to obtain a concrete sum, the costs are those of a simple cut and cover tunnel and do not involve major technical difficulties. The 38M€ of estimated cost are a small sum next to the 350M€ of *Girona*. It can be concluded that putting the railway underground in *Figueres* is economically feasible.

The situation of the railway in *Figueres* does not call for an urgent intervention, unlike in the three previously mentioned cities. The presence of the railway does constraint the city in terms of mobility and quality; yet this constraint is nowhere as severe as in those other three cities. The recommendation to the ministry of infrastructure is to consider and further study the possibility of putting the railway underground in *Figueres*, especially if the municipality commits to funding part of the project.

The railway in *Girona* should not be modified. Even if the project would not have as much disruption to the service during construction of the tunnel as in *Figueres*, where there would be severe disruption; costs are just too high to make the project feasible and justifiable. Unless it is the municipality who primarily funds the project, something which is not going to happen, the viaduct will most likely remain at it is for years to come.

As far as the other three cities goes; namely, *Lleida, Tarragona and Reus*; the main goal is the refurbishment of the surroundings of the railway. In all three cases, derelict rail facilities act as the border between railway and street, resulting in a very bad integration of the railway. This is a very common situation not only in these three cities but in many major cities across Europe. It is not tolerable and is most often due to the unwillingness of the rail authority to give up land to the municipality. Cooperation is therefore necessary. In the case of *Tarragona* and *Reus*, besides reducing the number of tracks to the strict minimum; building an underpass that enables access to the station from both sides of the tracks, which currently involves a long detour, is a very simple strategy yet a very effective one to alleviate the barrier effect.

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